

**Type A Accident
Investigation Board Report
of the February 13, 1997
Welding/Cutting Fatality
at the
K-33 Building, K-25 Site
Oak Ridge, Tennessee**

1.0 INTRODUCTION

1.1 BACKGROUND

On February 13, 1997, at approximately 11:10 a.m., a welder (referred to as "the Welder") using a cutting torch at the K-33 Building, Oak Ridge K-25 Site, Oak Ridge Reservation, was fatally burned after being totally engulfed in flames when his anti-contamination coveralls and blue general-purpose coveralls burned.

On February 13, 1997, a welder using a cutting torch was fatally burned when his anti-contamination coveralls caught fire.

On February 14, 1997, Tara O'Toole, M.D., M.P.H., Assistant Secretary for Environment, Safety and Health, U.S. Department of Energy (DOE), appointed a Type A Accident Investigation Board to investigate the accident in accordance with DOE Order 225.1, *Accident Investigations* (see Appendix A).

1.2 FACILITY DESCRIPTION

Contractor activities at the K-33 Building are managed by the DOE Oak Ridge Operations Office (OR). The facility in which this accident occurred is under the programmatic direction of the DOE Office of Environmental Management (EM). The current management and operating (M&O) contractor for the K-25 Site is Lockheed Martin Energy Systems, Inc. (LMES).

The K-25 Site, of which K-33 is a part, covers roughly 5,000 acres, or 14 percent of the Oak Ridge Reservation, and is approximately 13 miles from downtown Oak Ridge, Tennessee. The Site includes buildings that used the gaseous diffusion process to enrich uranium in the U²³⁵ isotope. In 1985, the gaseous diffusion process facilities were placed on standby and were shut down in 1987. Since 1987, efforts have been under way to evaluate cost-effective methods to decontaminate and decommission these facilities, while minimizing waste generation and the potential for future environmental issues.

Almost 90 percent of the available building space is currently

Nearly all of the available building space at the K-25 Site is either undergoing, or is planned for, decontamination and decommissioning.

undergoing, or is planned for, decontamination and decommissioning (D&D). Current activities of the K-25 Site gaseous diffusion process facilities principally involve passive storage of waste drums, surveillance and maintenance activities, and occasional removal of process equipment for shipment to operating gaseous diffusion plants.

K-33, the largest of the gaseous diffusion process facilities, occupies approximately 32 acres in the northwest section of the K-25 Site. Until 1985, the K-33 Gaseous Diffusion Building was used for uranium enrichment. Significant amounts (greater than 1 kg) of enriched uranium remain deposited in process equipment throughout the building. To minimize the risk of a nuclear criticality reaction, the deposits have been isolated. Hazardous and mixed wastes are stored in the building. There are few workers in the building on a daily basis.

The basic equipment unit in a gaseous diffusion plant, referred to as a stage, has three main components: an electric-motor-driven compressor, a converter containing a very large surface area of semi-permeable barrier material, and the process gas heat exchanger. A grouping of stages is referred to as a cell. The related piping systems connect eight equal-size stages to form a cell, which is enclosed in sheet metal. K-33 contains 640 stages grouped into 80 cells. The cells are grouped into units, and the units constitute a cascade. Exhibit 1-1 shows several of the remaining six stages comprising Cell 7 of K-33 at the time of the accident.

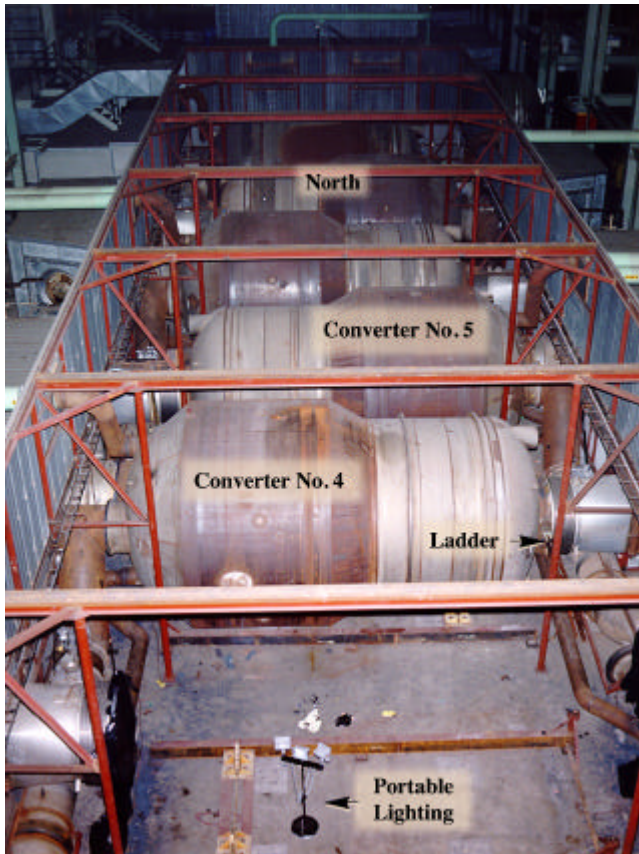
1.3 SCOPE, CONDUCT, AND METHODOLOGY

The Board commenced its investigation on February 17, 1997, completed the investigation on March 14, 1997, and submitted its findings to the Assistant Secretary for Environment, Safety and Health on March 19, 1997.

The **scope** of the Board's investigation was to review and analyze the circumstances to determine the accident's cause(s). The Board also evaluated the adequacy of the DOE and contractor's safety management system and work control practices.

The K-33 Building gaseous diffusion process is shut down; however, significant amounts of enriched uranium remain.

The Type A Accident Investigation began on February 17, 1997.



**Exhibit 1-1. View Looking North in Cell 7,
K-33 Building**

The **purposes** of this investigation were to determine the causes of the accident, including deficiencies, if any, in safety management systems and to assist DOE in understanding lessons learned to promote safety improvement and to reduce the potential for similar accidents.

The Board conducted its investigation, focusing on management systems, using the following **methodology**:

- Facts relevant to the accident were gathered through interviews and through document and evidence reviews.
- Burn tests of clothing similar to that worn during the accident were conducted.

- Event and causal factors charting,¹ along with barrier analysis²

The investigation determined the causes of the accident and developed judgments of need to prevent recurrence.

and change analysis,³ was used to provide supportive correlation and identification of the accident's causes.

- Based on analysis of the data, judgments of need for corrective actions to prevent recurrence were developed.

2.0 FACTS AND ANALYSIS

2.1 ACCIDENT DESCRIPTION AND CHRONOLOGY

2.1.1 Background and Accident Description

The accident occurred at approximately 11:10 a.m. on Thursday, February 13, 1997, at the K-33 Building when the Welder, who was using a cutting torch, became engulfed in flames. The Welder was employed by LMES. The work at the K-33 Building involved removing six converters from Cell 7 for shipment to Portsmouth/Paducah as spare parts. This work began February 8, 1997, and was scheduled to be completed by the end of March 1997, prior to the award of a contract under the re-industrialization program at K-25.

The accident occurred at approximately 11:10 a.m. on February 13, 1997, in Cell No. 7.

The scene of the accident was within Cell 7 of the K-33 Building (see Exhibit 1-1). A planning meeting for the removal of three "000" converters from K-33, Unit 8, Cell 7 was held on January 27, 1997 (four days after the Safety Work Permit was issued), and a subsequent Maintenance Job Request was issued on January 27, 1997. The cell roof, two converters, a small side panel on the east wall adjacent to Converter 3, and a small side panel on the west side adjacent to Converter 5 had already been removed from Cell 7 at the time of the accident. As a result of the work done in 1996 at K-31 [referred to as the Small-Scale Metal Recycle Project (SSMRP)], plus earlier extensive equipment replacement activities during operations prior to 1985, LMES had classified the removal

The removal of equipment from the cells was considered routine maintenance, and no specific job hazard analysis was prepared beforehand.

¹ Charting depicts the logical sequence of events and conditions (causal factors) that allowed the events to occur.

² Barrier analysis reviews hazards, the targets (people or objects) of the hazards, and the controls or barriers that management control systems put in place to separate the hazards from the targets. Barriers may be administrative, physical, or supervisory/management.

³ Change analysis is a systematic approach that examines barrier/control failures resulting from planned or unplanned changes in a system.

of converters and associated equipment from K-33 for this job as “routine maintenance.” Thus, no task-specific work plan or Job Hazards Analysis was prepared. The following permits were prepared: Safety Work Permit (January 23, 1997), Radiological Work Permit (February 7, 1997), and the daily Welding/Burning/Hotwork Permit⁴ for February 13, 1997. The workers initiated K-33 converter removal on February 8, 1997.

The job was about a week behind schedule, and the crew worked overtime on Saturday, February 8, 1997, and on Wednesday evening, February 12, 1997.

On February 13, 1997, the Service Supervisor (the first-line supervisor responsible for the workers on the job and conduct of the work) was not present at the daily safety meeting held by the welders at 7:00 a.m. Although not present at the meeting, the Service Supervisor signed a Burning Permit for the work to be conducted in the cell for that day. No designated fire watch was assigned on the permit.

The Service Supervisor signed the work permit, but did not assign a fire watch.

Four maintenance mechanics arrived at the K-33 Building around 7:50 a.m., electronically signed the Radiological Work Permit (RWP No. 970067), dressed in anti-contamination clothing, entered Cell 7, and prepared to remove Converter 3. They left the building for a short time because Converter 3 was not ready to be lifted out of the cell. They returned to the maintenance building for morning break at 8:30 a.m. The maintenance mechanics returned, and the welders first arrived at the K-33 Building at around 9:30 a.m. All workers except the Welder signed the Radiological Work Permit, dressed in anti-contamination clothing, and entered the radiological area. The Welder electronically signed the Radiological Work Permit at 9:57 a.m. and, dressed in anti-contamination clothing, entered the radiological area, arriving at Cell 7 at 10:35 a.m. After talking with radiological control technicians, he entered Cell 7 at about 10:55 a.m.

At the time of the accident, the Welder was wearing one set of underwear, one set of 100 percent cotton blue general-purpose coveralls, two sets of 100 percent cotton yellow anti-contamination coveralls, one pair of cotton liner gloves, one pair

At the time of the accident, the Welder was wearing three sets of coveralls, three pairs of gloves, four covers over safety shoes, a skull cap and hood, a personal air monitor, and a full-face respirator with an attached welding

⁴ Hereafter, “Welding/Burning/Hotwork Permit” is referred to as “Burning Permit.”

of latex gloves, one pair of terry cloth welder gloves, one pair of safety shoes, one pair of plastic booties, two pairs of plastic shoe

covers (scuffs), one pair of rubber totes, a skull cap, a hood, a full-face respirator, a personal air monitor, and a welding mask clipped to the respirator. Exhibit 2-1 shows a similarly outfitted welder.

Exhibit 2-1. Similarly Outfitted Welder

Maintenance mechanics had finished moving Converter 3 out of the



cell and were doffing their outer layer of anti-contamination coveralls at the contamination boundary control station just outside Cell 7. One welder (Welder 2) was in Cell 7 working on the northwest side of Converter 5. Another welder (Welder 3), upon leaving Cell 7, noticed that the Welder was changing his torch tips. The Welder then began to cut the clamps on the east end of Converter 4. Neither Welder 2 (in the cell) nor Welder 3 (out of the cell) was in direct sight of the Welder.

The Welder was using a cutting torch to remove one of the six remaining process converters and, at the time of the accident, was working on a ladder at the east end of Converter 4 (see Exhibit 2-2).

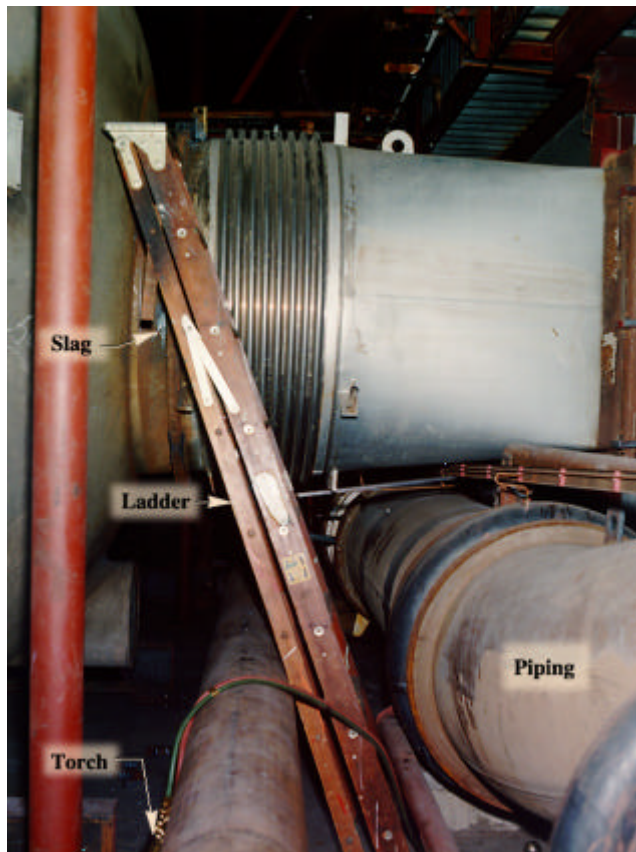
mask.

The Welder was basically working alone, out of sight of other workers.

No access panels had been removed from the east wall adjacent to Converter 4.

Exhibit 2-2. East End of Converter 4

No direct account of the accident was available, since there were no



eyewitnesses. The Board has reconstructed the most probable sequence of events (through extinguishing the flames by a maintenance mechanic), using the physical evidence, interviews, and results of burn tests. A schematic of the inside of Cell 7, the relative location of personnel, and the path of the Welder after he became engulfed in flames is shown in Figure 2-1. At approximately 11:09 a.m., a piece of hot slag or a spark ignited the Welder's anti-contamination coveralls at or somewhat below his left knee. At approximately 11:10 a.m., the Welder felt heat and noticed that the clothing on his left leg was on fire. The Welder attempted to put out the flames while he was still on the ladder. He came down the ladder, moved to the south side of Converter 4, and screamed for help while still trying to put out the flames. He removed his mask and respirator and screamed for help again. Because the respirator muffled the first scream, only the second scream was recognized as a distress call by one of the four maintenance mechanics outside Cell 7.

The Welder's outer coveralls ignited, but he did not know it for perhaps a minute or more. His first call for help was muffled by his respirator.

Two maintenance mechanics requested permission from a radiological control technician to enter Cell 7. One of them turned off the oxygen and acetylene cylinders of the Welder's torch, located outside Cell 7, while the other entered Cell 7, crawled under the piping, and saw the Welder, who was now standing on the cell floor northwest of Converter 1, totally engulfed in flames. While attempting to help the Welder remove his burning clothes, the maintenance mechanic's gloves caught on fire, so he stepped back and extinguished his own gloves by rubbing them together. At this point, the Welder began to run in a path that took him to the northeast side of Converter 1, where he fell to his knees on the floor of the cell (see Figure 2-1). The maintenance mechanic picked up a dry-chemical fire extinguisher and extinguished the flames at approximately 11:12 a.m.

When a worker entered the cell to help, the Welder was engulfed in flames. After the worker's gloves briefly caught fire, he extinguished the Welder's flames with a dry-chemical fire extinguisher.

2.1.2 Chronology of Events

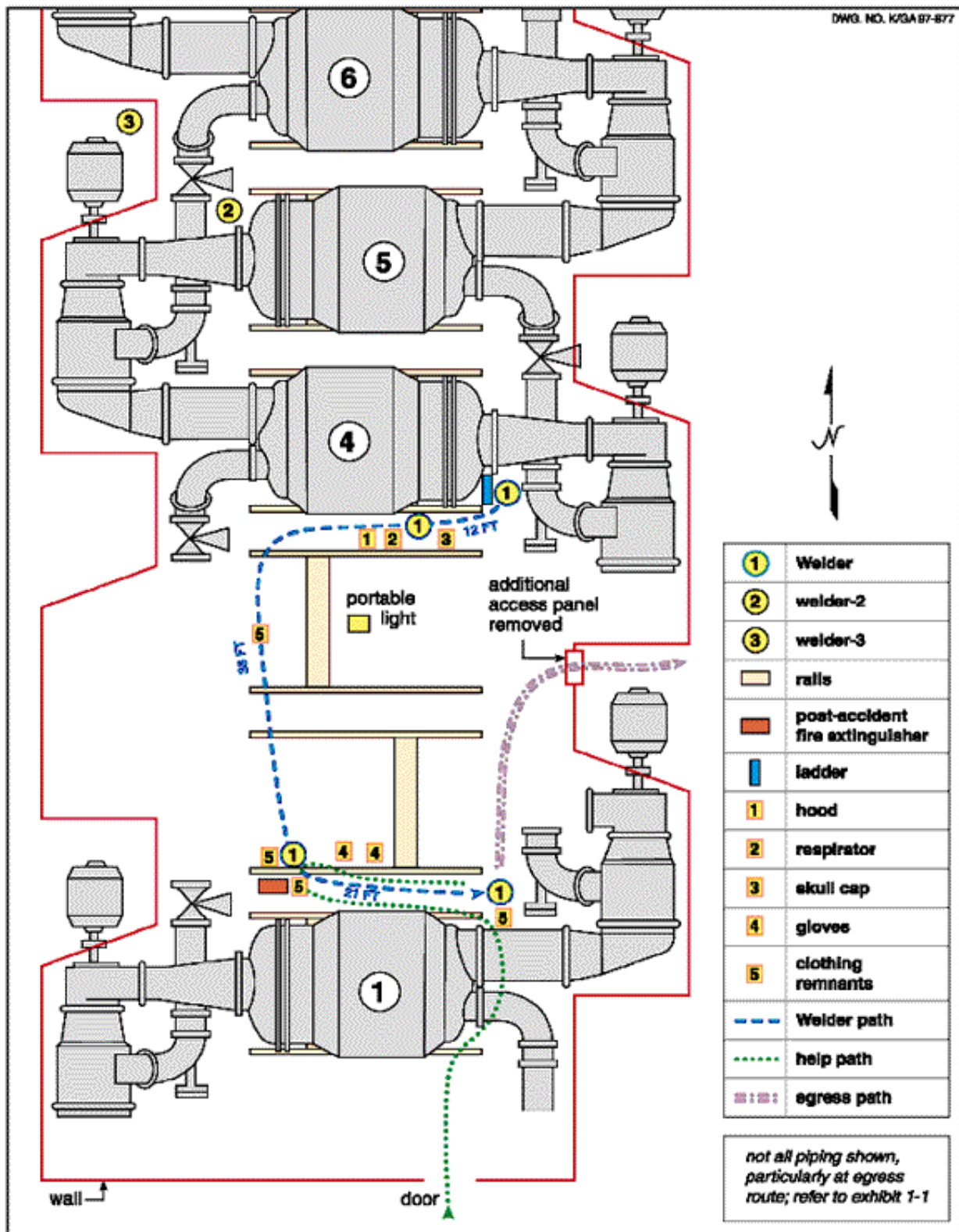
Figure 2-2 summarizes the chronology of significant events.

2.1.3 Emergency Response and Investigative Readiness

The Welder's burn injuries generated a response involving coworkers, Fire Department personnel, and Medical Facility professional staff. Pull-box and Station Nine calls brought Fire Department responders within minutes. Under difficult, restricted access conditions, first responders and follow-on Fire Department Emergency Medical Technicians rendered first aid to the Welder and extracted him on a stretcher from the K-33 Building. K-33 Building and Cell 7 layout obstacles prolonged patient removal. Medical personnel (doctor and nurse) examined him outside the building and treated him on the ambulance run to Methodist Medical Center Emergency Department. An intravenous catheter was inserted in the left wrist, and fluids were administered en route. The Welder was kept warm to avoid burn-related hypothermia and given oxygen to breathe. He was loaded aboard the ambulance at 11:46 a.m. (about 35 minutes after the accident), arriving at Methodist Medical Center in Oak Ridge at noon.

Obstacles in the cell and building hampered removal of the Welder to the ambulance.

Figure 2-1. The Welder's Location and Movement Within Cell No. 7



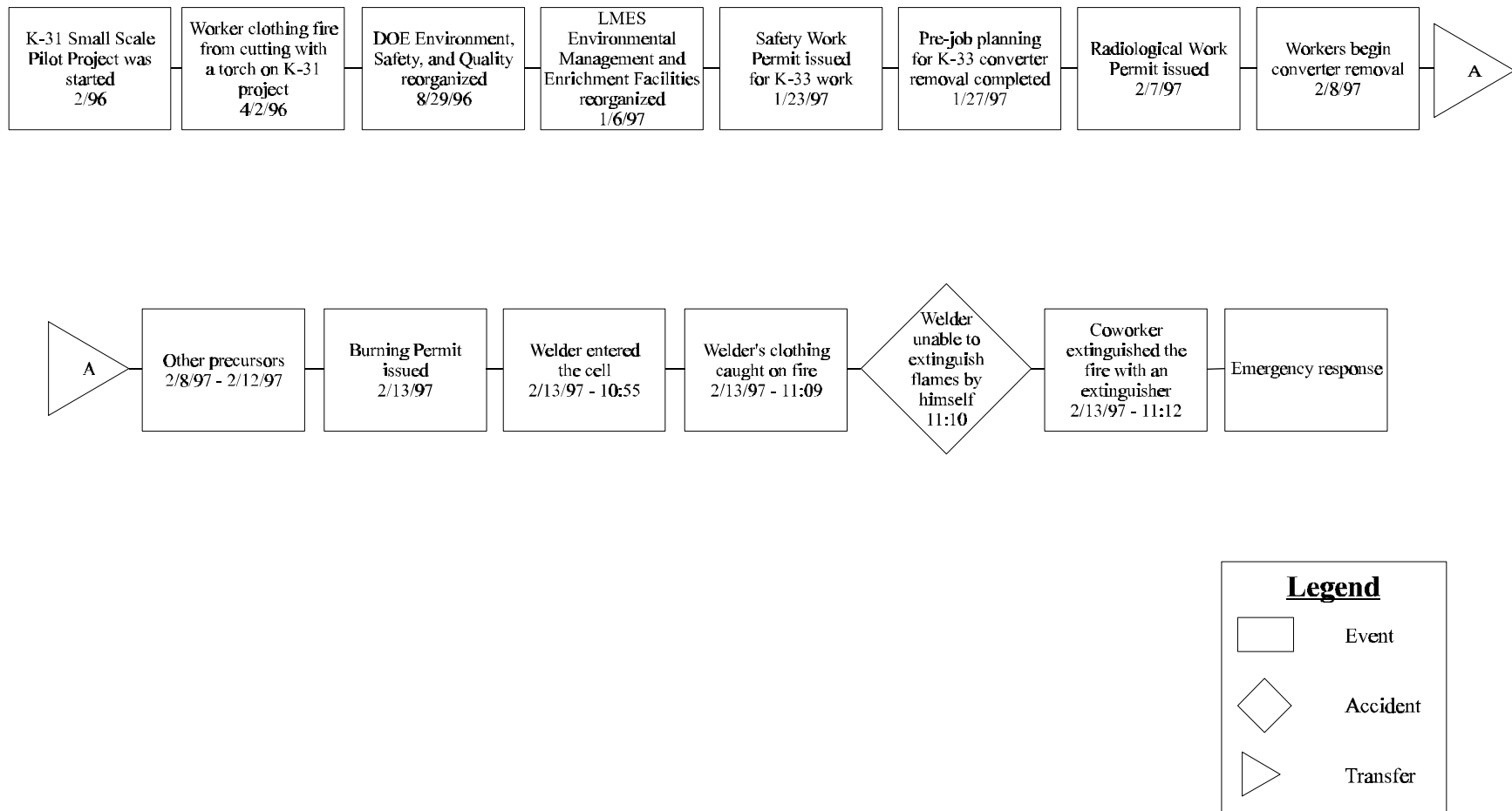


Figure 2-2. Summary Events Chart and Accident Chronology

The Welder was examined and surveyed by Radiation Emergency Assistance Center team members and was free of radioactive contamination. Emergency physicians and surgeons managed his medical care in the Emergency Department, and a general surgeon continued medical and surgical management in the Intensive Care Unit. After 4½ hours of stabilization care, the decision was made to transfer him to Erlanger Burn Center in Chattanooga. Air transport was requested through rotary and fixed-wing carriers, but could not be done because of icy weather. Ultimately, ground transport was arranged for the patient transfer to Erlanger.

The Welder was burned over 95 percent of his body. He died the next day.

The Welder suffered third-degree burns over 95 percent of his body. He died at 10:41 a.m. on February 14, 1997, from acute respiratory distress syndrome.

The overall quality of the accident response effort on February 13, 1997, was satisfactory and provided the Welder opportunity for survival, if his burn wounds had not been so extensive. However, egress from Cell 7 was problematic because of poor illumination and the confined nature of the work site. The difficult extraction from the cell/building accounted for delay in transport to the Medical Center. Twenty minutes of the rescue time were spent getting patient-removal gear to Cell 7 and maneuvering the stretcher-borne, 215-pound Welder over and under pipes. A nearby cell panel opening also had to be enlarged for egress. Without the obstacles, the egress difficulties from Cell 7, the physical distances involved, and the lack of basic first-aid gear in the building, the extraction time could have been shortened by approximately ten minutes.

Overall accident response was satisfactory. Quicker evacuation of the victim, while possible, would not have changed the outcome.

LMES took prompt, appropriate, and effective actions following the accident to preserve the integrity of the accident scene, collect evidence, and prepare for an accident investigation. The investigative readiness of LMES met the requirements of DOE Order 225.1, *Accident Investigations*.

The contractor took appropriate actions in maintaining the accident scene.

2.2 HAZARDS, CONTROLS, AND MANAGEMENT SYSTEMS

A review of previous occurrences at K-25 reported in DOE's Occurrence Reporting and Processing System since 1991 revealed that the leading root causes were management systems and personnel error. There has been one Type A accident investigation at K-25 since 1991 (November 22, 1992, fatality) and five Type B investigations. The root causes of the November 22, 1992, fatality were that line management did not establish responsibility for safety, effective work controls were not used, and the safety culture

resulted in hazards going unrecognized.

The Nuclear Regulatory Commission, Naval Reactors Program, National Institute of Science and Technology, National Fire Protection Association, and National Safety Council were contacted and indicated that they knew of no reported incidents involving ignition of anti-contamination clothing with resultant fatalities during cutting and welding operations. A 1988 Occupational Safety and Health Administration (OSHA) report on selected cutting- and welding-related fatalities identified only one fatality from clothing ignited by sparks and molten metal. The report covered 217 cases involving 262 fatalities from 1974 through 1988. Review of recorded DOE occurrences indicated that none involved fatalities in cutting and welding operations due to normal or anti-contamination clothing fires.

Records of six agencies, plus the DOE, indicated only one similar fatality.

2.2.1 Industrial and Worker Safety

The following facts relate to industrial and worker safety issues that had an impact on the accident:

Personal Protective Equipment (Clothing Flammability)

- The Welder was wearing personal protective equipment, as previously noted in Section 2.1.1. OSHA requirements in the Federal regulations for personal protective equipment do not specify a need for fire-retardant clothing for welding/cutting operations.
- The blue general-purpose coveralls met the requirements of 16 CFR 1610 for normal flammability, Consumer Products Safety Commission Class 1 clothing ("having no unusual burning characteristics" as "generally accepted by the trade"). The anti-contamination coveralls met LMES specifications for such clothing (MS-HPD-001-A) and had no flammability requirements specified. Some LMES personnel believed that the company-issued, anti-contamination clothing was fire-retardant. This misinterpretation may be a result of the LMES clothing specifications for the blue general-purpose coveralls (Consumer Product Safety Commission Class 1, normal flammability). However, this classification only requires that the clothing have no unusual burning characteristics and is designed only to eliminate the use of any "dangerously flammable clothing textiles" in ordinary clothing.
- Flammability of the company-issued, blue general-purpose coveralls was first raised as an issue at the monthly K-25 Company-Union Safety Advisory Committee meeting in January

Fire-retardant clothing was not required or used.

1995. As a result:

- In April 1995, Norvell Corporation representatives met with maintenance, safety, welder, and union representatives to discuss the use of flame-retardant blue coveralls. Several pairs of flame-retardant blue coveralls were ordered to be used by electricians, welders, and maintenance mechanics on a trial basis.
 - At the September 1995 K-25 Company-Union Safety Advisory Committee meeting, union representatives reported that the blue coveralls, worn by six different welders, were scratchy and hot, even after laundering. They also noted that sparks from welding operations penetrated the fabric more easily and more often than the current, company-issued, non-flame-retardant blue coveralls. At that time, it was decided to continue using the company-issued blue coveralls, and the issue was closed.
- Flammability of the company-issued, anti-contamination coveralls was raised in a monthly K-25 Company-Union Safety Advisory Committee meeting in May 1995.
- At the meeting, a union representative displayed a sample pair of the fire-retardant, anti-contamination coveralls obtained from Norvell. These coveralls were pure cotton and were treated with a fire retardant. The material was guaranteed by the manufacturer for 25 industrial washes as long as chlorine bleach was not used. These anti-contamination coveralls were similar to those used at other DOE sites, such as Portsmouth and Paducah.

- The sample pair of fire-retardant, anti-contamination coveralls was placed in the Industrial Safety Office for the workers to view. However, no records indicate the final disposition of this issue. It appears that neither the Committee, the Union, nor LMES revisited this issue after May 1995.
- Neither the general-purpose nor the anti-contamination coveralls were fire-retardant. (See Section 2.3 for the results of clothing tests conducted by an independent testing laboratory at the request of the Board.)
- The personal protective equipment specified on the Radiological Work Permit was consistent with that for a high- contamination area, as described in the LMES K-25 *Site Radiological Control Program Manual* and in Procedure RCO-AP-8.02, *Radiological Work Permits*, Revision 1, Appendix A, *Anti-Contamination Clothing Guidelines*.
- National Fire Protection Association Standard 51B, *Safety in Cutting and Welding Operations*, does not identify requirements for personal protective equipment for cutting, welding, and brazing.

Work Permits

- A Safety Work Permit (SWP), a Radiological Work Permit, and a Burning Permit were prepared for the work being performed. The SWP for the welding work in Cell 7 indicated that site fire protection staff would conduct a site evaluation. However, there was no evidence that an in-cell evaluation was conducted. The responsible fire protection engineer for the Cell 7 hazard evaluation did not view the work site inside the cell prior to signing the SWP.
- The Burning Permit for the day of the accident did not identify a fire watch for the work. According to the Service Supervisor, he orally assigned four maintenance mechanics to the Cell 7 work, including fire watch duties. However, because the Service Supervisor did not attend the daily safety meeting, the Board has no evidence that these instructions were given. According to the maintenance mechanics, they were not aware that they had been assigned fire watch duties. In addition, none of the maintenance mechanics were inside the cell at the time of the accident.

Although required in the permit process, no work site fire hazard evaluation was performed, and no fire watch was assigned.

- The bases for posting the area inside the cell as a high-contamination area were radiological surveys performed by the Radiological Control Organization and possible contamination resulting from cutting into the radiologically contaminated process system.
- Evidence indicated that radiological control technicians performed continuous coverage of the work as required by the Radiological Work Permit.

HEPA Filter Placement

- The Radiological Work Permit required that a radiological control technician check the placement of the high-efficiency particulate air (HEPA) local exhaust ventilation, which had to be within one foot of cutting, grinding, and burning operations. There was no evidence that this check was completed prior to the accident.
- The Board's review of the accident scene revealed that the HEPA local exhaust ventilation vacuum unit on the east side of Cell 7, and its associated hose, could not be properly placed from outside the cell, nor could it reach the work area on the east side of Converter 4.
 - Five clamps had already been cut on the east side of Converter 4 at the time of the accident.
 - The position of the HEPA unit, the use of the east side access panel for Converter 3, and the length of the hose available (approximately 15 feet) indicate that the HEPA local exhaust ventilation was not being used at the time of the accident or prior to the accident when the five clamps were cut.

The HEPA filter was not used as required by the permit.

OSHA regulations and guidance emphasize that, whenever possible, engineering controls to reduce exposure to workers must be evaluated and implemented before administrative procedures and personal protective equipment are deployed. LMES Program Description, SH-152PD, *Occupational Safety and Health Program*, Section 4, states that the order of precedence for this process is: (1) substitute less hazardous processes, (2) apply engineering controls, (3) use administrative controls, and (4) use personal protective equipment.

The contractor's safety program emphasized use of personal protective equipment over the implementation of engineering controls.

All previous converter removals were similar, which would facilitate the design and use of easily movable welding shields or enclosures

to minimize the spread (distribution) of slag from this cutting. Alternative methods (other than using a torch) could also have been substituted. These engineering controls and alternative processes apparently were not considered because of the emphasis placed on the use of personal protective equipment.

Most fire protection and cutting/welding standards, including DOE and LMES standards, concentrate on the property protection aspects of the hazards and do not specifically address the need for and the type of personal protective equipment to resist flame and heat. However, OSHA requirements do indicate that personal protective equipment should be appropriate for the hazards being encountered.

The only standard found that was relevant to fire-retardant personal protective clothing is the American National Standards Institute (ANSI) Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*. This standard recommends that heavier-weight materials, such as wool or heavy cotton, which are more difficult to ignite, be worn during cutting and welding work. It further recommends that cotton be chemically treated to reduce its combustibility and warns that washing may reduce fire retardancy. It also offers specific construction recommendations for clothing used in cutting and welding to reduce the clothing's ignition potential, such as no cuffs or uncovered pockets. However, this standard is not a mandatory DOE standard, nor is it referenced as an applicable standard in OSHA Federal regulations regarding personal protective clothing.

The emphasis on property protection also minimizes the importance of training fire watch personnel in alternative methods for extinguishing a fire, such as the drop-and-roll method or enveloping a person in a heavy woolen "fire blanket" to smother the flames.

No regulatory, DOE, or LMES requirements for fire-retardant clothing were applicable to the fire hazards associated with the work being performed in Cell 7 at the time of the accident. However, some specific fire protection concerns inherent in the work activities to be performed within Cell 7 required professional evaluation (e.g., fire extinguisher placement and inspection and Life Safety Code considerations) but were not adequately reviewed by fire protection staff. The fire potential represented by the combustible clothing worn by the welders may not have been recognized by the fire protection staff unless they witnessed the clothing burn tests or had been advised by the welders that their clothing had caught on fire during previous jobs. Neither was the case here.

One national consensus standard found on flame-retardant clothing is not mandated by DOE or referenced as applicable by OSHA.

No regulatory, DOE, or LMES requirements for use of fire-retardant clothing exist.

The K-25 Company-Union Safety Advisory Committee has reviewed issues related to personal protective equipment since at least 1993. In 1994 and 1995, OSHA implemented new requirements for the flammability of electrical workers' personal protective equipment. The Committee, after input from the workers who evaluated sample materials, decided not to use the flame-retardant, blue general-purpose coveralls and opted to continue using their current coveralls. Flame-retardant anti-contamination clothing was also reviewed at a Committee meeting in May 1995. However, based on interviews, the Board determined that the minutes from the meeting were not totally correct. In 1995, the Committee evaluated anti-contamination clothing from the perspective of heat stress, not flammability. A sample made available to the union members also happened to be flame-retardant. However, the Committee did not recognize the importance of the flammability issue for the anti-contamination clothing; therefore, the issue was not pursued.

The site's contractor/union safety committee evaluated anti-contamination clothing from the perspective of heat stress, not flammability.

The *K-25 Site Radiological Control Program Manual* was developed in accordance with the *DOE Radiological Control Manual* (DOE/EH-0256T, Revision 1). It identifies the actions necessary to ensure proper interpretation and implementation of all provisions of regulations and regulatory guidance relevant to the K-25 Site Radiological Control Program.

The following requirements in the *K-25 Site Radiological Control Program Manual* were consistent with the guidance of the *DOE Radiological Control Manual*:

- "Protective clothing, as prescribed by the RWP [Radiological Work Permit] is selected based on the contamination level in the work area, the anticipated work activity, worker health considerations, and regard for nonradiological hazards that may be present.
- "The use of personal protective equipment or clothing (including respiratory protection) beyond that permitted by the RCO [Radiological Control Organization] for radiological control purposes detracts from work performance and is contrary to ALARA [As Low As Reasonably Achievable] principles and waste minimization practices. Such use is not authorized.
- "Company-issued clothing, such as work coveralls (blue's, scrubs, or khaki's) and shoes, are considered the same as personal clothing and are not used for radiological control purposes.

The LMES Radiological Control Program Manual limits multiple levels of personal protective equipment from a waste minimization standpoint only.

- “Outer personal clothing are [sic] not to be worn under anti-C [anti-contamination] clothing: (1) for entry into High General Area Removable Contamination Areas, (2) during work conditions requiring splash resistant anti-C [anti-contamination] coveralls, or (3) during work conditions requiring two pairs of anti-C [anti-contamination] coveralls.”

Guidance for Personal Protective Equipment Programs is addressed in 29 CFR 1910.120, *Hazardous Waste Operations and Emergency Response*, Appendix C, *Compliance Guidelines*, which states “[t]he use of PPE [personal protective equipment] can itself create significant worker hazards, such as heat stress, physical and psychological stress, and impaired vision, mobility, and communication. For any given situation, equipment and clothing should be selected that provide an adequate level of protection. However, over-protection, as well as under-protection, can be hazardous and should be avoided where possible.”

The use of blue general-purpose coveralls, worn by workers in Cell 7 on the day of the accident, was not prescribed by the Radiological Work Permit prepared and used for the work.

A Radiological Work Permit is an administrative mechanism that establishes the radiological controls to be used in conducting radiological work activities. It describes the scope of the work to be performed, required personal protective equipment, radiological survey data applicable to the work area, and other pertinent special instructions. It does not appear that consideration was given to risks for fire hazards during welding and burning operations associated with (1) using multiple layers of personal protective clothing (e.g., anti-contamination clothing) and (2) using blue general-purpose coveralls, in addition to the personal protective equipment prescribed by the Radiological Work Permit. Use of the radiological personal protective clothing appears to have been based primarily on the contamination level inside the cell rather than on consideration of all potential hazards, such as fire.

The Radiological Work Permit did not address risks from the use of multiple levels of personal protective equipment.

Implementing the requirements of the K-25 *Radiological Control Program Manual* in the work controls, planning for the welding and burning work at K-33, evaluating the potential hazards associated with the use of multiple layers of anti-contamination clothing, and prohibiting the use of the blue general-purpose coveralls under the anti-contamination coveralls would not have precluded the Welder's anti-contamination clothing from catching fire. However, it might have permitted the Welder to recognize that he was on fire earlier than he did. Although 29 CFR 1910.120 applies to hazardous waste

operations and emergency response, it was the only guidance that considered the use of personal protective equipment as a potential hazard to workers. The Board was unable to locate any Federal regulations, DOE Orders/rules, or LMES K-25 policies that addressed the application of radiological personal protective equipment for welding and burning operations inside radioactive contamination areas.

Limiting multiple levels of personal protective equipment would not have prevented the fire, but might have allowed the Welder to know more quickly that his clothing was on fire.

2.2.2 Work Planning and Controls

The DOE Implementation Plan for Integrated Safety Management, dated April 18, 1996, states that safety management activities can be grouped into five core safety management functions:

- Define the scope of work
- Identify and analyze the hazards associated with the work
- Develop and implement hazard controls
- Perform work within controls
- Provide feedback on adequacy of controls and continuous improvement in defining and planning work.

These five core safety management functions provide the necessary structure for any work activity that could potentially affect the public, the workers, and the environment. The degree of rigor needed to address these functions varies with the type of work activity and the hazards involved. An analysis of work planning and controls for the K-33 converter work applicable to the accident in relation to the five core safety management functions follows.

Define the Scope of Work

LMES used a maintenance job request to define the scope of the work to be performed. However, the Board found that line management responsibility and accountability for safety was lacking at both the Oak Ridge Operations Office and LMES. Within the Operations Office, no organization or individual assumed or was assigned the responsibility for managing and monitoring the work to be performed at K-33. Within LMES, the Board found that organizations and individuals responsible for the building/facility were not involved in planning the work and therefore were unaware of any impact the work might have on their safety envelope. No single organization within LMES served as a focal point to ensure that all hazards were identified, safety permits were prepared in accordance with LMES procedures, and appropriate hazard controls were put in place. As a result, no complete work package was developed that adequately translated the job mission into work, set

Five core safety management functions for work planning/control were analyzed.

As a result of a lack of clarity

safety expectations, and prioritized tasks. In addition, because of a recent reorganization and downsizing, personnel with adequate training or experience were not assigned to the job.

Identify and Analyze the Hazards Associated With the Work

OSHA [in 29 CFR 1910.132(d)] requires the employer to assess the workplace to determine whether hazards are present, or are likely to be present. These regulations also require that “the employer shall verify that the required workplace hazard assessment has been performed through a written certification that identifies the workplace evaluated; the person certifying that the evaluation has been performed; the date(s) of the hazard assessment; and which identifies the document as a certification of hazard assessment.”

K-25 Site Standard Practice Procedure, “Safety Work Permit SPP-5401,” Revision 3 (Change 5, effective date November 27, 1996) states that the issuing authority (i.e., the individual authorized to have operating jurisdiction over the equipment or facility where the work covered by the permit was to be performed) “will determine the safety requirements by using job safety analysis, safety plans, and any other approved documents as an aid.” However, the responsibility to ensure that a Job Hazards Analysis has been performed in accordance with LMES Instruction SH-118INS, Revision 0, dated July 10, 1996, is not clearly identified.

LMES Instruction SH-118INS describes the process for conducting a Job Hazards Analysis, provides guidance regarding conditions under which a new Job Hazards Analysis should be performed, and states that the “supervisor” is responsible. The process described by this instruction includes assembling a multidisciplinary team of workers and safety professionals, documenting individual work steps for the job, identifying the hazards for each step, and specifying the controls for each hazard. A Job Hazards Analysis to this level of detail was not performed for SSMRP, and no Job Hazards Analysis was performed for the K-33 converter removal.

During the SSMRP work at K-31, industrial safety/industrial hygiene personnel were permanently assigned to the job and monitored the actual cutting operations at the work site to evaluate the hazards and controls for the work.

LMES Instruction SH-118INS contains adequate guidance for performing a Job Hazards Analysis. However, the individual responsible (issuing authority or supervisor) for ensuring that a Job Hazards Analysis has been or is to be conducted in accordance with

in line management responsibility and accountability for safety, an incomplete work package was prepared.

A number of sources mandate the need for a Job Hazards Analysis for the type of work performed in the K-33 cell, but none was performed.

this instruction is not clearly defined. Consequently, such a Job Hazards Analysis was not performed for the K-33 converter removal work. It is the Board's judgment that a properly conducted multidisciplinary Job Hazards Analysis in accordance with LMES Instruction SH-118INS, with experienced workers participating, might have identified all the hazards to the Welder.

In this case, because of an unclear assignment of responsibility and because of lack of specific guidance with regard to the identification of routine/non-routine work, no Job Hazards Analysis was performed.

It should be noted that the Board conducted a multi-agency search for other instances where a welder died due to ignition of his or her clothing. Only one such incident was found in private industry, possibly leading to a widespread lack of appreciation concerning the hazards involved in this welding/cutting operation. Since workers had not reported earlier clothing fires, supervisors had not recognized the rather frequent occurrence of such fires, and there was little indication of a similar hazard in the literature. The recognition of the interrelationship between the fire hazard and the personnel protective equipment required for this job would be dependent on the intelligence and forethought of those conducting the analysis.

No individual was assigned responsibility for ensuring the conduct of a Job Hazards Analysis.

Develop and Implement Hazard Controls

The work documents prepared during planning for the K-33 converter removal work included a Maintenance Job Request, a Radiological Work Permit, an SWP, and a Burning Permit. The permits specified the hazards controls for the work. Review of these documents revealed that:

- The Radiological Work Permit required the use of anti-contamination clothing. However, the personal protective equipment specified for the Welder did not meet the criteria that it be based on the anticipated work activity, worker health considerations, and regard for the non-radiological hazards that may be present, as required by the K-25 Site *Radiological Control Program Manual*.
- A task-specific work plan was not prepared for K-33 converter removal work, because the work was classified as "routine maintenance" within the "skill of the craft"; consequently, K-25 Site Maintenance Division Administrative Procedure MDP-AP-0002, Rev. 5, dated January 1, 1996, did not require a work plan. This procedure did not contain adequate criteria for

The work documents dealt

identifying maintenance work that is routine versus non-routine and/or within the “skill of the craft.” Appropriate criteria are necessary to ensure that a task-specific work plan is prepared, when appropriate, based on the complexity of the work and the hazards that are present.

- The work documents specified no alternative cutting methods, engineered controls, or specific personal protective equipment to protect the workers from sparks or hot slag generated during cutting operations. The work documents contained no provisions to ensure adequate ingress and emergency egress for personnel or equipment, even though the cell had only one entrance, and human entry through that entrance was restricted by the piping configuration. Removal of roof panels and side panels was also necessary for equipment removal.
- The work documents did not require installation of lighting inside K-33, Cell 7, which had no lighting prior to the start of work. Additional lighting was installed as a result of oral direction from Industrial Safety/Hygiene. However, after the work started, the adequacy of lighting was not evaluated either for the work being performed or for personnel egress in an emergency.
- Although required by LMES Procedure ESS-FP-111 (Rev. 1), a fire watch was not identified on the Burning Permit for the work being performed on the day of the accident. A fire watch is a designated individual trained in fire-watch duties, who, for welding/cutting activities, is required to be dedicated to this task. Reviews of three other Burning Permits for work in the cell on the days prior to the accident revealed that two did not have a fire watch identified. The service supervisor in charge of the work is responsible for identifying the fire watch on the Burning Permit.

Converter removal work was sufficiently complex, with a variety of personnel hazards, to require preparation of a task-specific work plan. Had the work not been classified as “routine maintenance” and within the “skill of the craft,” a work plan might have been prepared, and adequate provisions for concerns such as lighting and ingress/egress could have been specified. The work plan also could have provided a means to convey lessons learned during past work (such as that for the SSMRP at K-31) to the workers involved in K-33 converter removal.

It is the Board’s judgment that LMES procedures do not contain adequate criteria for identifying maintenance work that is routine

inadequately with safety issues, such as administrative and engineering controls, lighting, and fire watch.

Classifying the work as “routine” may have circumvented the consideration of some hazards and controls.

versus non-routine and/or within the “skill of the craft.” In this case, the complexity of the work, the relative unfamiliarity of the welders with performing tasks in the prescribed protective equipment, and the significant differences between the K-33 configuration and that of the more recent similar work would seem to make dependence on “skill of the craft” questionable. In addition, some hazard controls that were identified for the work were not implemented.

Perform Work Within Controls

The Board could find no evidence of a pre-job safety meeting that included the Service Supervisor, all the craft disciplines, and appropriate safety personnel assigned to monitor the work.

A number of specified controls were bypassed.

The Welder wore his blue general-purpose coveralls beneath two sets of anti-contamination clothing. This is prohibited by the *K-25 Site Radiological Program Control Manual*, Attachment 2 to Section 3.8.

Burning Permits, issued for converter removal work from February 11 to 13, 1997, were to be signed by the Service Supervisor and the Issuing Authority indicating that the precautions identified had been fully implemented and verified. On the day of the accident, the Service Supervisor signed in both capacities. The Board considers the Issuing Authority as the single point of contact responsible for the safety of all work to be performed, and this individual should have performed the verifications and signed the Burning Permit, along with the Service Supervisor. In addition, the verification spaces on the form were not checked; moreover, the Supervisor had not been at the work area (K-33, Cell 7) on February 13, 1997, prior to the accident, where he would have to go to determine whether the precautions identified on the Permit had been fully implemented.

No fire watch was identified, nor was a fire watch present in the cell at the time of the accident, as required by LMES procedures.

The Industrial Hygiene Department was not notified prior to cutting operations. Consequently, the industrial hygiene surveys, required by the SWP, were not accomplished.

As noted above, several actions specified by the work documents were not performed. Had the workers been adequately supervised, these actions could have been accomplished and appropriate controls placed on the work.

Provide Feedback on Adequacy of Controls and Continuous Improvement in Defining and Planning Work

Interviews revealed that the work being performed at the time of the accident was considered similar to that previously performed during the SSMRP at Building K-31 in 1996. Both jobs involved the cutting of piping and support structures and removal of converters using an overhead crane. During the SSMRP work, an entire cell (ten "00" converters, compressors, motors, and associated piping and supports) was removed. A task-specific work plan was included as a part of the SSMRP Maintenance Job Request. The work was initiated on May 15, 1996, and completed on July 3, 1996. Because it had been several years since major removal of equipment, the work at SSMRP was fully planned and documented to enable application of lessons learned to future similar work. However, the two jobs differed in several ways. For K-33 converter removal work, the cell walls remained in place, while for SSMRP, the exterior walls were removed before cell equipment was disassembled. The equipment in K-33 was also much larger than in K-31. Another key difference was that the equipment from K-33 was to be reinstalled in a nuclear facility, while for K-31, the metal was to be recycled.

A project report, prepared at completion of the SSMRP work, documented lessons learned during the SSMRP work. These lessons learned included the need for developing and using a work plan for future similar work, developing specialized cutting tools, not assigning fire watches, and reducing anti-contamination coverall requirements to one pair rather than two during burning/cutting operations. There was no evidence that either the SSMRP project report or the lessons learned from the project were used by personnel involved in the K-33 work.

None of the maintenance workers assigned to K-33 converter removal had worked on the SSMRP. The supervisor had never supervised welders before, and he had not been trained on the use of Burning Permits.

Interviews revealed that anti-contamination clothing had caught fire in similar work during the SSMRP at K-31. Anti-contamination clothing also caught fire at K-33 due to molten metal (slag) dropping/splashing on the clothing. For example, several days before the accident, a welder's bootie caught fire, and the day before the accident, the Welder's shoulder sleeve caught fire, burned through both sets of anti-contamination clothing, and scorched his general-purpose coveralls. These and many similar incidents were

Though different in key ways, the work in K-33 was considered similar to previous work in K-31.

Lessons learned in the K-31 work were not applied to the work in K-33.

Welders' clothing had caught fire previously at both K-31 and K-33, but the incidents were not reported.

never reported as “near misses” through the occurrence reporting system, nor were they reported as injuries, since they resulted in either no burns or only minor burns.

Summary

An analysis of the facts leads to the conclusion that the maintenance work planning process and associated controls for the K-33 converter removal work did not ensure that an adequate Job Hazards Analysis was completed before the work began. Thus, measures and controls to mitigate the work hazards were not developed or implemented, and the work was not performed with appropriate controls.

The absence of clearly defined line management responsibility and accountability for safety caused failures in translating the job mission into safe work practices, setting safety expectations, and allocating trained and experienced personnel. Since line management did not ensure that an adequate Job Hazards Analysis was completed prior to the work starting, measures and controls to mitigate the hazards for the work were not developed or implemented. In turn, this caused the work to be performed without appropriate controls. The requirements for this process were specified in LMES instructions and K-25 site procedures, but were not implemented during the work. Furthermore, lessons learned from previous work were not adequately evaluated, documented, or incorporated into the planning for K-33 converter removal work. If the problems workers experienced with anti-contamination clothing catching on fire had been adequately analyzed, and if the lessons learned had been documented, communicated, and appropriately incorporated into the planning for K-33 converter removal work, the accident might have been avoided. More fundamentally, weaknesses in the safety management system allowed the Welder’s safety to depend on the single mitigating factor of a property-protection-oriented fire watch that, while required, was not routinely implemented.

The Board considered the limited history of fatalities associated with the ignition of anti-contamination clothing during welding/cutting operations, the lack of requirements regarding the use of flame-retardant anti-contamination clothing, and the failure of existing fire watch requirements to emphasize personnel safety responsibilities. Based on these considerations, the Board could not conclude that even a work planning/control process that met the five core management functions of the DOE Implementation Plan for Integrated Safety Management would have prevented this accident. However, the Board did conclude that without such a structured

In summary, the planning process for the K-33 work did not involve required analysis of hazards, did not assure adequate controls, and did not identify crucial lessons learned.

work planning/control process, as was the case for the work being performed in Building K-33, the opportunity to identify the clothing fire hazard was not provided, thereby assuring that it would not even be considered.

2.2.3 Policies and Procedures

LMES Policy Statement ES-EH-100 was in place for the establishment and implementation of environment, safety, and health (ES&H) policies and to direct that all ES&H efforts be carried out cooperatively and with the degree of consistency specified in policies, standards, and procedures. LMES committed to conduct operations effectively, in compliance with applicable ES&H Federal and state laws, orders, and regulations, and in a manner consistent with the associated hazard. LMES Program Description SH-152PD further outlines the methods used to protect personnel in the fields of occupational safety, industrial hygiene, and fire protection. In the program description, LMES committed to implement this program for consistency with the requirements of Federal regulations, Lockheed Martin Corporation, Inc., policies, and applicable DOE Orders.

- LMES Procedure SPP-5401 describes the SWP process for the evaluation and control of potential, or actual, hazards associated with work activities, such as the removal of process equipment in the K-33 Building and the protocol for establishing appropriate protective measures.
- A Job Hazards Analysis was not used to determine the safety requirements associated with the converter removal work in Cell 7 as prescribed by Procedure SPP-5401.
- The issuing authority for the SWP did not review the work requirements and protective measures listed on the permit with the new Service Supervisor in charge of the work on the day of the accident to ensure that both were in agreement prior to issuing the Permit.
- There was no supervision to monitor the workers or the cell on the day of the accident to ensure that the tasks were completed in compliance with the SWP, as required by LMES Procedure SPP-5401.
- LMES Industrial Safety and Health, Industrial Hygiene, Fire Protection, and Nuclear Criticality Safety staff signed the SWP.
- In some instances, special instructions were documented on the

Relevant policies and procedures are in place but were not followed.

SWP by LMES safety and health staff (i.e., “Industrial Hygiene to monitor initial openings for hydrogen fluoride. Extended burning/welding may require carbon monoxide monitoring. Respiratory protection required during initial process equipment openings. Industrial Hygiene may perform sampling for metal exposure. Heavy equipment operation may require carbon monoxide. Notify Industrial Hygiene prior to starting work.”)

- Not all LMES safety and health staff who signed the SWP entered the cell to evaluate and identify potential hazards and determine the necessary protection measures.
- Actual work performance did not comply with the special instructions on the SWP:
 - Industrial hygiene staff were not contacted to survey the cell prior to the commencement of work activities.
 - Industrial hygiene surveys were not performed in the cell to evaluate associated hazards.
- OSHA regulations require that personal protective equipment be used appropriate for the hazards being encountered.
 - No personal protective equipment was mandated on the SWP for the fire hazards associated with the work being performed on the day of the accident.
 - Neither LMES Procedure ESS-FP-111, “Welding, Burning, and Hotwork Fire and Health Protection,” Revision 1, dated April 11, 1994, nor a safety bulletin issued by the DOE Office of Environment, Safety and Health (EH) in June 1991 (*Fire Prevention Measures for Cutting/Welding Activities*, DOE/EH-0196, Bulletin 91-3) addresses personal protective equipment. In addition, the EH Bulletin focuses only on property loss prevention rather than on personnel protection.
- LMES Procedure ESS-FP-111, Revision 1, applies to all welding, burning, or hotwork operations conducted at LMES sites for construction, repair, or maintenance activities and establishes requirements for ensuring that an effective control program is in place to prevent injury, loss of life, and property damage from fire, as well as adverse health effects initiated by welding, burning, or hotwork operations. A review of this procedure revealed:

- The requirement to identify a fire watch for all welding, burning, or hotwork operations is identified, but personnel-monitoring responsibilities for the fire watch during operations are not specified.
 - The requirement for maintaining a line of sight with the workers at a distance that would enable timely emergency response is not addressed.
 - Immediate first-aid response or any fire-extinguishing techniques, other than the use of fire extinguishers (e.g., fire blankets, drop-and-roll technique) are not addressed.
 - The use of radios or other devices for fire watches during emergency situations is not addressed.
 - A designated fire watch was not assigned or listed on the Burning Permit by the Service Supervisor.
- The Service Supervisor did not inspect the cell and verify that all precautions were taken prior to initiation of work on the day of the accident.

A Job Hazards Analysis is a tool for systematically identifying the hazards associated with the individual steps of an identified activity/operation, documenting the preventive measures taken to control each hazard, and planning mitigation strategies for imminent danger scenarios. An SWP is required to establish safety boundaries and controls to ensure that adequate protection is provided for workers performing specified work that creates the potential for special or unusual hazards. The responsibilities, minimum requirements, and guidelines for preparing, approving, issuing, and using an SWP at the K-33 Building are described in K-25 Site Procedure SPP-5401. Cross-references to other associated procedures and work control processes, such as the Job Hazards Analysis and Burning Permit, are identified in Procedure SPP-5401.

Work performed on the day of the accident was not in accordance with applicable procedures (Procedures SPP-5401 and ESS-FP-111, Revision 1). Potential job hazards were not identified through a Job Hazards Analysis, the condition of the work area inside the cell was not adequately evaluated by ES&H disciplines and the Service Supervisor, and mitigation actions for emergency situations were unclear and/or were nonexistent. A designated fire watch was neither assigned for the job nor listed on the Burning Permit; also,

the role of the designated fire watch was not clearly defined in procedures.

Failure to provide adequate procedures and to effectively implement them at all levels of LMES prevented a clear understanding of expectations and the associated requirements. A Job Hazards Analysis could have identified specific safety hazards and mitigation strategies for the work performed on February 13, 1997. The failure to use a designated fire watch contributed to the Welder's delayed detection of the fire hazard. In addition, failure to follow the existing procedures for completing and using the required SWP and Job Hazards Analysis, in addition to inadequate supervision and monitoring of the work activities, led to conditions in which all hazards were not identified and were therefore unmitigated.

2.2.4 Human Factors, Training, and Qualifications

The LMES Burning Permit and fire watch processes in place include training and procedures for work like that being performed on February 13, 1997. Review of training lesson plans and procedures revealed that, in some instances, the lesson plans contained detailed instructions that were not in the procedures.

The training for the Burning Permit process indicates that one responsibility of service supervisors is to personally inspect the work area to ensure that all precautions are fully implemented. Following this inspection, the "verified" column on the Permit is to be completed.

Fire watch training for welding, burning, and hotwork includes detailed instructions for fire watches. The training includes instructions that if the fire watch leaves the work site, he/she should stop all burning, welding, and hotwork, or otherwise ensure that another fire watch is assigned to the work site. However, this was not documented in LMES procedures, and there was no fire watch inside the cell at the time of the accident.

The Welder's training was up-to-date. The Welder had no physical, mental, or other impediments that impacted his performance. The Welder's peripheral vision and sense of smell were impaired by the requirement to wear a full-face respirator under a welder's mask while he was working (see Exhibit 2-3). The two sets of anti-contamination coveralls, in conjunction with the blue general-purpose coveralls, resulted in a bulky garment with many folds and creases that could have captured sparks or molten slag produced from the cutting/welding process (see Exhibit 2-1). Further, his

Procedural inadequacies and failure to follow procedures allowed hazards to remain unidentified and unmitigated.

Some fire watch instructions that appear in training do not appear in procedures.

ability to recognize (by sensing heat) that he was on fire was reduced by the multiple layers of clothing, which provided insulation when the outer coverall ignited. This was confirmed in interviews with other welders, who indicated that because of their personal protective equipment, including respirator and welder's mask, they invariably feel the heat of the fire before they see it.

The victim's ability to sense a fire was limited by his protective equipment.

Training Module 11655 states that supervisors are to "inspect the area where the burning and welding will be done." The Board located three Burning Permits issued for this job, dated February 11, 12, and 13, 1997. The Service Supervisor logged onto the Radiation Work Permit for this job only on February 11 and 12, 1997. Therefore, the Service Supervisor could not have inspected the work area on February 13, as indicated on the Permit. However, the training did not indicate that this inspection must be done every time a permit is issued. If conditions change or additional hazards are present, they would not be addressed on the permit and/or by the supervisor unless his inspection was done on a daily basis. The day before the accident, the Welder's anti-contamination coveralls caught fire, and a coworker extinguished the fire before it caused injury. This was not reported, so no new special instructions or additional guidance were entered on the Permit used on the day of the accident to address this unrecognized hazard.

The work area was not inspected prior to signing the permits, and relevant safety incidents were not reported.

Interviews conducted with employees revealed uncertainty concerning job security at K-25 due to downsizing and reorganization. The work force at K-25 is getting smaller, and employees' concerns about retaining their jobs may be a deterrent to reporting incidents of clothing fires that do not result in injuries. Because of the downsizing and LMES reorganization, there may also be a decrease in the workers' ability to focus on the job at hand.

Concerns about job security may have affected incident reporting.



**Exhibit 2-3. Welder's Outfit with Hood and Respirator
(Closeup)**

Review of training records for employees present at the time of, or involved in, the accident indicated that fire watch training had lapsed (expired August 20, 1994) for one of the maintenance mechanics present at the job site. The Facility Managers/Service Supervisors Training Module (11655) advises supervisors that fire watches should be trained annually. The Service Supervisor who was assigned to the work had not completed the Facility Managers/Service Supervisors training, which addresses responsibilities of supervisors/issuing authorities who complete Burning Permits. However, the training is not specific enough to ensure that supervisors/issuing authorities understand what fulfilling these responsibilities means (i.e., verifying that precautions are implemented, identifying a fire watch), nor is this training required. It is only recommended training. Therefore, neither the Service Supervisor nor the Issuing Authority was trained on the importance of identifying a fire watch and documenting it on the permit.

The duties of the fire watch were not being carried out according to LMES training doctrine during the time the work was being done; neither the responsible Service Supervisor nor the Issuing Authority had completed the recommended training to facilitate understanding of their job responsibilities. Thus, another administrative barrier that could have prevented the accident was not in place.

The combination of personal protective equipment that restricted sensory perception and the lack of a designated fire watch

Fire watch training for supervisors and issuing authorities is not required; therefore, responsibilities are not well understood.

significantly reduced the protective barriers against fire hazards.

2.2.5 Management Systems

Contractual Background

The converter removal work in K-33 was conducted as part of a “work for others” project under various memoranda of understanding between the contractor for United States Enrichment Corporation (USEC), Lockheed Martin Utility Systems (LMUS), and LMES. Under a lease agreement between DOE and USEC, process equipment needed at Portsmouth and Paducah is available from K-25 facilities. Under this arrangement, LMUS identifies needed components and equipment (such as the converters in K-33) and negotiates costs and schedules with LMES, who then performs the equipment removal and subsequent shipment to LMUS. From OR’s perspective, funding is made available to LMES and LMUS via a “Program 40” financial code. The K-33 equipment removal work under “Program 40” was funded by USEC and administered via the OR Office of Planning and Budget.

The work at K-33 was part of a “work for others” project.

LMUS requested six “000” converters; this equipment was available from K-33, Cell 7. Various memoranda between OR Office of Enrichment Facilities, LMES, and LMUS in 1996 and 1997 discuss the general task, and work was executed by LMES and LMUS consistent with contract provisions. However, OR basically delegated project arrangements to LMES and LMUS to negotiate. LMUS provided funding authorization; however, no firm schedules were identified, and project details were generally handled informally by telephone. There is evidence that the OR Office of Enrichment Facilities was aware of the work.

Under contract with OR, LMES maintains the K-25 Site and is bound to implement (among other contractual provisions) safety and health requirements, as specified in the contract (Section H-16) and the referenced Standards/Requirements Identification Documents. These requirements are, in turn, translated by LMES into operating procedures for completing work activities.

Oak Ridge Operations Office Roles and Responsibilities

OR organizational functions are described in generalized *Mission and Functions Statements*. However, lines of authorities and specific roles and responsibilities for activities categorized as “work for others” are not addressed. No evidence of other formal protocols or written instructions for DOE management and control

of “work for others” activities was identified. There was no evidence that OR has assumed line management responsibility for the K-33 converter removal work.

Portsmouth and Paducah programmatic responsibilities in OR are assigned to the Office of the Assistant Manager for Enrichment Facilities. Although aware of the equipment removal activities, the OR Office of Enrichment Facilities was not aware of the project planning or the identification of safety requirements, nor were they involved in safety and health monitoring of the converter work in K-33. During interviews, Enrichment Facilities management stated that such activities were not assigned to them and that they had not assumed any project responsibilities. Therefore, this Office did not communicate that equipment removal activities were being undertaken to the OR office with landlord responsibilities.

For more traditional projects where OR provides direct funding, responsibilities and authorities established for OR elements involved in safety management are more clearly described. However, in this K-33 converter removal “work for others” activity, OR organizations below the first management level did not have clear expectations and understandings as to their safety responsibilities and authorities for planning, monitoring, and oversight. As a result of OR’s recent transition to a matrix project organization, safety and health oversight is not emphasized by the OR Office of Environment, Safety and Health, which provides routine technical and oversight support to line organizations as requested.

OR Office of Enrichment Facilities management assumed that the OR Office of the Assistant Manager for Environmental Management and the K-25 Site Office would provide safety management and oversight of “work for others” being performed in K-33. However, this was not the case, since the K-25 Site Office was not actively engaged in monitoring or tracking the K-33 converter removal work, as discussed below.

Office of the Assistant Manager for Environmental Management Roles and Responsibilities

During Board interviews, the OR Site Manager and the Assistant Manager for Environmental Management indicated that K-33 and the converter removal work responsibility would fall under the purview of the K-25 Site Office. During his interview, the K-25 Site Office Manager stated that this responsibility resided with the Environmental Restoration Division and was not within the purview

Roles and responsibilities for “work for others” are not defined.

Safety responsibilities and authorities for the K-33 “work for others” were not well understood below the Operations Office Manager level.

of the K-25 Site Office's landlord program. Further, the Assistant Manager for Environmental Management reinforced his understanding of responsibilities for K-33 by discouraging any Board followup with the Environmental Restoration Division Manager, because he was confident that the Environmental Restoration Division was not involved with the work.

The Board determined that landlord responsibilities for K-25 (non-environmental restoration, sitewide facilities, support organizations) were assigned to the OR Office of the Assistant Manager for Environmental Management and to the K-25 Office. This Office, while responsible for surveillance and maintenance of the K-33 Building and activities undertaken therein, did not manage or monitor the converter removal work; therefore, they could not assure that appropriate requirements specified in the DOE authorization basis or other facility parameters (such as fire protection, OSHA compliance, electrical safety, and criticality safety) were adequately identified during planning and properly controlled during the work. In the absence of this involvement, the integrity of building safety systems and appropriate administrative controls while the building was in the "surveillance and maintenance" mode could not be assured.

OR K-25 Site Office personnel, while generally aware of the work activities, were not involved with the planning, did not inspect the work area, and did not provide oversight/monitoring of the converter removal work in Cell 7. No Environmental Restoration Division facility representative oversight was performed for this work, nor was there evidence that any oversight activities had been performed within K-33 for several months prior to the accident. Reviews of audit/assessment plans and reports for 1996 revealed that K-25 was evaluated from a sitewide systems and/or functional standpoint (e.g., fire protection, waste management, lockout/tagout, safety permit processes). However, there also was no evidence of K-25 Site Office oversight for the equipment removal projects within K-33.

Because of widespread differing perceptions of responsibility expressed by various levels of OR management, it was not clear that any OR organization assumed responsibility for the K-33 converter removal work. These unclear lines of responsibility do not meet the Department's integrated safety management policies and principles, and they demonstrate that line management responsibility for the project was not assumed by OR.

There was no clear understanding of what OR organization was responsible for the work at K-33.

The Oak Ridge K-25 Site Office did not guide oversight/monitoring of the converter removal work at K-33.

Lockheed Martin Energy System Roles and Responsibilities

On January 6, 1997, LMES Environmental Management and Enrichment Facilities implemented comprehensive **organizational changes** based on four subordinate organizational components: Program Planning and Integration; Project Execution; Business, Financial and Subcontract Management; and Project Support. The organizational structure reflected OR plans to implement a matrix approach to project and safety management. These changes also responded to reduced resource levels, both realized and expected, which were anticipated to result in more efficient and effective work execution by matrixing needed resources to the projects. The converter removal work in K-33 was managed by Project Support.

OR line management did not assume responsibility for safety.

Interviews with senior LMES management revealed that the normal **process for project definition and execution** was expected to formally follow from the OR Assistant Manager for Enrichment Facilities to LMES Project Execution, which would task LMES Project Support. This was not the case for the converter removal work in K-33. In fact, the process flowed from the OR Assistant Manager for Enrichment Facilities directly to LMES Project Support.

The **specific process** employed to communicate work scope, schedule, and project details of the converter removal work in K-33 was generally informal. Existing LMES policies and procedures did not address specific details for “work for others” projects, nor did they provide the detail necessary to clearly and unambiguously establish roles, responsibilities, and lines of authority to interface with other necessary disciplines and crafts. The sequence of planning and requisite level of interaction with and feedback from others in the organization could not be discerned by reviewing documentation for the work at K-33.

The normal LMES process for project definition and execution was not followed.

The intricate **organizational interrelationships** in LMES established in January 1997 were being initiated and communicated to those affected at the time of the accident. Many of those affected, who had management responsibility for the activities that led to the accident, were unsure of their responsibilities at the time of the accident investigation. Since the January 1997 reorganization, functional roles and responsibilities were not understood below the LMES Oak Ridge Site Management Office (K-25) level. An additional factor involves job security concerns expressed during interviews by a significant number of LMES employees. LMES and K-25 have undergone significant reductions in the labor force, resulting in a decreased core competency base and experience level;

additional reductions are ongoing. The January 1997 reorganization resulted in a number of personnel assigned to new roles with unclear line, administrative, and project reporting lines and authorities, resulting in general confusion as to their specific responsibilities for project work. Further, as part of its reindustrialization efforts, DOE is negotiating with a consortium led by British Nuclear Fuels Limited and Manufacturing Sciences Corporation to take control of three large process buildings (including K-33) for decontamination and equipment salvage. The role of LMES and the potential fate of its employees in this effort are not clear.

LMES reorganization led to lack of clarity in roles and responsibilities.

These changes caused unclear or insufficient understanding of LMES line management **safety oversight** roles and responsibilities, including those for project planning and management and for oversight of the work. Consequently, first-line supervisors, safety personnel, and crafts employees may have assumed risks in the absence of clear direction and oversight by their managers. For example, inspection and evaluation of the actual work site inside Cell 7 by responsible supervision and safety personnel (who did not understand they had such responsibilities) were not adequately performed prior to and during the work. Except for health physics, there was no safety and health oversight of the work.

Senior **Project Support** management informally assigned the Manager of External Customer Projects as Project Manager for the K-33 converter removal work. The Project Manager understood his role to be that of a “coordinator” or “facilitator,” responsible for maintaining customer satisfaction. Responsibility for budget and schedule was clearly understood; however, safety and health responsibilities were not. The Project Manager assigned a technical assistant as the Issuing Authority. In this role, the Issuing Authority is expected to perform the details of scoping, creating the Maintenance Job Request to initiate the work and obtaining the SWP and Burning Permit. However, these roles were dispersed among the planning organization, the maintenance organization, and the Service Supervisor. Thus, there was no single focal point who was responsible for and/or knowledgeable of all activities involved in the work.

Safety oversight within LMES was inadequate.

The **planning** organization, after cycling through several different planners for the converter removal work as a result of downsizing, finalized the Maintenance Job Request on January 27, 1997. The planners categorized the activity as “routine maintenance” and decided that no additional instructions were needed. The package was accepted by the Service Supervisor in the maintenance organization, who executed the work using welding and maintenance

Responsibility for and understanding of the work at K-33 were dispersed within the LMES organization.

mechanics. He had no prior experience supervising welders. The Project Manager and Issuing Authority were not included in this effort; moreover, there is no evidence that their review/approval was solicited or provided regarding the adequacy of the work package or that they received copies of the final Maintenance Job Request.

With no apparent input from the Issuing Authority, planners also selected the safety disciplines needed to support the work and identified necessary permits. Interviews disclosed that both the planners and the Issuing Authority assumed that they were responsible for initiating the request for permits. The Issuing Authority also perceived that his responsibility was to assure that signatures were completed on the SWP, not to verify that safety disciplines had adequately performed inspections of the cell before signing the permit.

The **role of an Issuing Authority** is also not clearly defined. A listing of Issuing Authorities (effective December 31, 1996) disclosed that at least nine organizations have personnel designated for this capacity, including the K-33 Building Operator and the K-33 converter removal work Issuing Authority. The SWP and Burning Permit procedures do not consider a lead organization for signing the permits as the Issuing Authority. Therefore, there was no clear understanding of the Issuing Authority concept by personnel involved in the converter removal project.

At the **worker** level, LMES management controls, planning activities, and completion of the converter removal work relied on a base level of skill, referred to as “skill of the craft,” to perform work safely. However, there was no common understanding at LMES regarding the specific knowledge and skills represented by “skill of the craft.” Further, there was no commonly acknowledged delineation between knowledge regarded as “skill of the craft” and that which should be regarded as job-specific or not “routine.” The involved workers’ experience with other equipment removals was not adequate to compensate for the insufficient safety management controls and assumption of risk by employees on the K-33 removal work: the Service Supervisor had no previous experience with supervising welding; one of the welders had no experience with converter removal; none of the workers for this job had been involved with the most recent similar work at the SSMRP; and this was the first time these welders had been required to wear this level of personal protective equipment while removing converters under the conditions found in Cell 7.

Within LMES Project Support, the Surveillance & Maintenance

Planning decisions were made largely by people outside of project management and/or not experienced with the work.

The involved workers lacked the experience to compensate for inadequacies in management controls.

Operations for the D&D organization is **responsible for the K-33 Building**—that is, for ensuring that the building is adequately maintained in terms of authorization basis, system and component integrity, waste storage, OSHA compliance, and environmental requirements. Functionally, this organization assigns a Building Operator who is responsible for the building. The Building Operator for K-33 at the time of the accident had been on the job for approximately one month; the prior Building Operator for K-33 was terminated as a result of downsizing. Interviews and a review of records revealed that neither of these individuals nor their staff of operators were included in the planning or monitoring of the K-33 converter removal work. Although mid- and senior-level management expressed, during interviews, an expectation that building operators/operators would be involved in the job planning and monitoring of the work, this did not occur.

The responsible LMES building operator was new to the job and was not involved in work planning and monitoring.

LMES has promulgated an Occupational Safety and Health Program Description in SH-152PD. The program is based on five tenets: management leadership, employee involvement, worksite analysis, hazard prevention and control, and safety and health training. Expectations are clearly stated for these general areas and include line management accountability for safety and identification of workplace hazards through the preparation of a Job Hazards Analysis. Various other policies and procedures generally articulate line management responsibility for safety and health. Evidence indicates that specific line management responsibilities for the converter work in K-33 were never formally established and were neither effectively communicated nor understood by management and workers.

LMES line management responsibilities for the work were not established, communicated, or understood.

The facts surrounding this accident include a variety of **safety management system breakdowns** in work planning, hazard evaluation, communications, and establishment and implementation of adequate work controls. The inadequacies included many examples of poor procedural implementation, beginning with pre-job planning and continuing through the failure to assign a fire watch to the project on the day of the accident. For the K-33 converter removal work, management followup on their written commitment to safety has not been effective.

The **chain of line management** and the attendant safety and health responsibilities were not clear to project management, K-33 building operations, planners, or the Service Supervisor. From the safety and health perspective, project management relied on planners, and planners relied on safety and health disciplines; however, not all safety and health disciplines had interaction with project

LMES work planning, hazard evaluation, communication, and work controls were ineffective.

management. Also, none of these groups had interaction with K-33 building operations. No one person or group understood and/or functioned as the central point for managing the project; thus, there was confusion regarding who was responsible. Because there was no overall direction, voids in line management responsibility for safety occurred throughout the work planning process, culminating in the accident.

No one LMES person or group understood and/or functioned as the central point for managing the project from a safety perspective.

2.3 BURN TEST ON WELDER'S CLOTHING

Based on witness interviews, the Board was concerned about the relatively short time it took for the Welder's clothing to be consumed. Of particular interest to the Board were the following: (1) the possible effects of laundering on the anti-contamination clothing worn by the Welder, (2) the timeline from ignition to the point of extinguishing the flames, and (3) the possible insulating effect of multiple layers of clothing, as it may affect the wearer's sensation of heat from the fire.

To resolve the laundering issue and/or to determine whether any accelerants or hydrocarbon compounds were present in the clothing worn by the workers in K-33, material from new and used clothing was tested at the request of the Board. Mass spectrometer tests of the clothing were conducted by Southwest Research Institute, San Antonio, Texas. The results of these tests indicated that the blue general-purpose coveralls and the yellow anti-contamination coveralls were of normal flammability and that laundering affected the chemical constituents in the materials in only minute, insignificant quantities. No accelerants or abnormal amounts of organic materials were found.

Laundering was found to have had no effect on the flammability of the outer coveralls.

To answer the remaining questions regarding the flammability issues, the Board requested a burn test. This test was also conducted by Southwest Research Institute using mannequins dressed in new and used clothing matching that worn by the Welder on the day of the accident. The mannequins were dressed with one set of underwear, one set of 100 percent cotton blue general-purpose coveralls, two sets of 100 percent cotton yellow anti-contamination coveralls, and other clothing as described in Section 2.1.1.

A burn test was conducted to determine how fast the coveralls burned and how wearing several layers of coveralls would affect the wearer's ability to detect the fire.

Thermocouples were placed between clothing layers at various anatomical locations. An electric heat coil, simulating a piece of hot slag, produced ignition. The left leg of the outer garment was ignited (location of fire initiation was based on the Welder's communication with paramedics and witnesses after the accident), and temperatures were recorded while the mannequin was filmed,

using video photography, to correlate flame spread with recorded temperatures.

Wisps of smoke were noted in 8 to 12 seconds, and the first few flames were seen at 30 seconds. Examining the data, extrapolating between the surface temperature of the mannequin and that of a person's skin (70°F and 90°F, respectively), and recognizing that the change in temperature with time was the most important factor, it was apparent that a 20-degree adjustment of the temperature readings was necessary in assessing the time it took for the Welder to sense the heat of the fire. Therefore, assuming that a welder would recognize a 30°F increase in temperature as "hot" and 50°F as "abnormally hot," then 100°F and 120°F, respectively, on the mannequin skin surface would be the equivalent threshold for the welder. Using these assumptions, the test data indicated that the worker might suspect a clothing fire by sensing heat at the following post-ignition times:

	30-degree change	50-degree change
Mid-thigh	65 seconds	80 seconds
Knee-inside	75 seconds	90 seconds
Groin area	140 seconds	150 seconds

Observing the extent of the fire at the elapsed time of 80 seconds on multiple mannequin test runs shows that containment or eradication by the Welder alone would be doubtful, if not impossible. In the Board's judgment, at 90 seconds from ignition, the extent and speed of the fire could only be controlled with fire- extinguishing equipment (e.g., fire blankets, fire extinguishers). Therefore, even if the worker felt the heat of the fire as early as 65 seconds into the event, he/she would have only 10 to 25 seconds to put it out before outside help would be necessary to extinguish the fire. At 120 seconds, the clothed mannequin was totally engulfed along the center axis, both front and rear, from the knee to the face. The fire continued to grow, and by 145 seconds, the shoulders and the clothing hood were in flames. A review of the test simulation videos shows approximately 90 to 95 percent of the clothing consumed in about 3½ to 4 minutes from ignition. This is consistent with the actual fire involved in the accident (see Exhibit 2-4, Remnants of the Welder's Burned Coveralls).

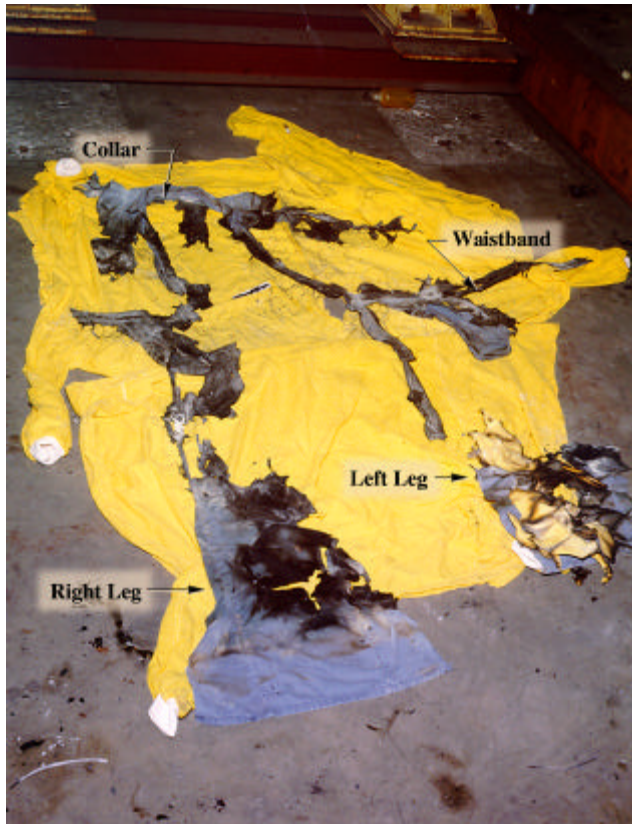
The test showed that by the time the wearer could feel the heat of the fire, he would not be able to extinguish it himself.

Exhibit 2-4. Remnants of the Welder's Burned Coveralls

It is important to note that the tests performed do not, and could never, actually duplicate the accident scenario that evolved at the accident scene. For example, the test was performed on a static mannequin, but much faster burn rates would be expected if the tests simulated a person in motion (running), thereby further ventilating the fire.

Results of the burn tests revealed that very high temperatures were attained quickly on the outer layers of the anti-contamination clothing, while the temperature at the skin level remained nearly the

The outer anti-contamination coveralls do not provide protection from fire.



same. The multiple layers of clothing effectively insulated the Welder from the heat and seriously impaired early detection of the fire. The burn tests also indicated that the anti-contamination and general-purpose coveralls worn by the Welder and other K-25 LMES welders did not, by themselves, provide any fire protection as personal protective equipment for the hazards of cutting, welding, and other hotwork. The flammability characteristics of the anti-contamination clothing made this clothing inappropriate for the cutting and welding operations being conducted at the time of the accident.

The Board determined that although the variables in a simulated test such as this are many and preclude precise measurement of the time

the Welder sensed the heat of the fire, the information from the simulation tests provides reasonable insight about the short time the Welder had to identify the fire and put it out before it became uncontrollable. Once this brief response window slipped by, only help from another worker, a fire watch, could have altered the outcome.

2.4 BARRIER ANALYSIS

A barrier is defined as anything that is used to control, prevent, or impede process or physical energy flows and that is intended to protect a person or object from hazards. The barrier analysis conducted by the Board addressed three types of barriers associated with the accident: administrative barriers, management barriers, and physical barriers. These barriers either failed or were missing. Successful performance by any of these barriers would have prevented or mitigated the severity of the accident. The barriers that failed are summarized in Figure 2-3. Appendix B provides details of the analysis.

Administrative Barriers

Safety staff did not perform a Job Hazards Analysis to ensure that hazards associated with the work activities were identified and evaluated, as required by LMES procedures and instructions. That is, the SWP process was not followed in its entirety for the work. Because converters had previously been removed in K-33 during the 1980s and more recently at K-31 for the SSMRP, management and participants in the work planning process considered this to be a routine activity; therefore, a Job Hazards Analysis (including onsite inspection) and work plan were not developed. The Burning Permit was improperly completed and

Administrative, management, and physical barriers were examined.

Administrative barriers that failed are Job Hazards Analysis, work planning, and training.

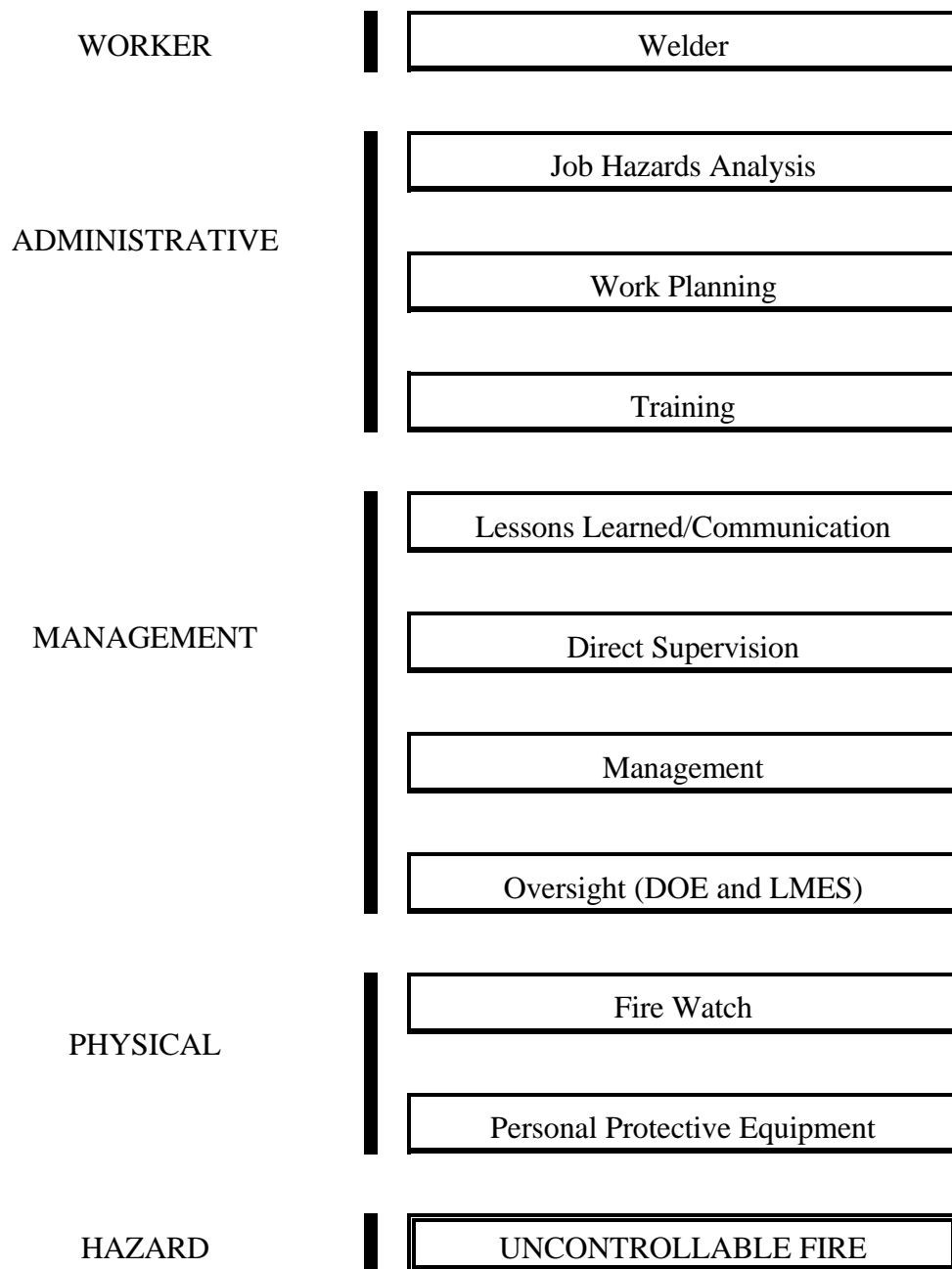


Figure 2-3. Barriers That Failed

was not validated, and a fire watch was not designated on the Permit. The Service Supervisor was not experienced, nor had the Issuing Authority for the permit or the Service Supervisor been trained in the Burning Permit process.

Management Barriers

Lessons learned from similar work activities and accidents were not incorporated into the work planning by planners, management, supervisors, or workers who prepared and carried out this work package. Precursors to this accident were not reported or communicated to management. Management was unaware of the fire hazard that existed, because employees were reluctant to report incidents and near misses. In addition, lessons learned from other work activities were not communicated effectively.

Management barriers that failed are communication of lessons learned, direct supervision, management, and oversight.

Supervision did not ensure that the workers understood safety requirements for the work, nor did they adequately verify that safe work processes were being implemented at the job site. A pre-job safety meeting with all people involved was not conducted. Lack of supervision for the work activity at the time of the accident was a failed barrier.

Reorganization of LMES and DOE, as well as their changing missions, changed the roles, responsibilities, and authorities of management to the extent that they were not clearly communicated or understood. Thus, important management and oversight barriers were less effective. The safety management processes failed because appropriate levels of management were not aware of the work being performed, nor did they understand their own roles and responsibilities below the senior management levels. Processes in place to ensure worker safety were not carried out or used effectively, and the normal oversight processes were not implemented.

Physical Barriers

Although required, no fire watch was assigned on the Burning Permit, and the Welder was alone at the time of the accident. In addition, the Department's requirements for a fire watch did not emphasize personnel protection. The personal protective equipment required by the Radiological Work Permit consisted of multiple layers of anti-contamination clothing and a full-face respirator. This selection of multiple personal protective clothing actually created a safety hazard. Non-radiological safety hazards were not considered when the determination for personal protective equipment was made as required by LMES safety policy. None of the three layers of clothing provided to and worn by the Welder were fire-retardant.

Physical barriers that failed are fire watch and personal protective equipment.

The clothing burned rapidly, and the multiple layers acted as insulation, reducing the Welder's ability to detect the fire. The Welder's mask and respirator also limited his ability to sense fire on his person.

2.5 CHANGE ANALYSIS

A change analysis was conducted to determine changes or differences that may have contributed to the accident. The results of the analysis are provided in Table 2-1.

Table 2-1. Change Analysis

Change or Difference		Analysis	
Planned/Normal	Present	Difference	Analysis
Job Hazards Analysis is performed for each job by interdisciplinary/ integrated team, and personal protective equipment is selected based on all hazards of the job.	No integrated Job Hazards Analysis was performed for this job, and personal protective equipment was selected without coordination by all safety disciplines.	Hazards for the work were not identified.	Failure to identify all hazards and appropriate personal protective equipment contributed to the accident.
Dedicated fire watch is assigned on all Burning Permits.	No fire watch was designated on the Permit.	No personnel were assigned to provide protection to the welders by observing fires either on welders or in the work area in the cell.	The absence of a fire watch was a factor in the accident.
Safety personnel perform a walk-through and evaluate the work area to determine the hazards prior to preparing the SWP.	Applicable safety disciplines did not perform a walk-through and inspection of the work area prior to preparing the Permit.	Safety personnel did not know the current condition of the cells and the inherent hazards of the job.	The lack of a thorough evaluation of the work area in the cell to identify hazards and safety measures (e.g., lighting, access/egress, fire extinguishers, communications) and subsequent provision of appropriate worker protection by safety personnel may have contributed to the severity of the accident.
Employees report injuries and near misses to their supervisors.	Employees did not report injuries or near misses.	Not all injuries or near misses were being reported.	Hazardous conditions were not known by management and continued without corrective action being taken.

Table 2-1. Change Analysis (Continued)

Change or Difference		Analysis	
Planned/Normal	Present	Difference	Analysis
DOE and LMES safety and health personnel are assigned to provide periodic observation and oversight of the work activities as part of line management oversight.	No safety and health personnel were assigned to observe the work activities, and there was no LMES or DOE oversight, except for the health physics organization.	There was inadequate safety and health oversight of the work.	Line management oversight did not adequately assure that safety requirements were implemented.
Supervisors are experienced, trained, and effective in communicating safety goals to the workers.	The Service Supervisor was not experienced, trained, or effective in communicating safety goals to workers.	The Service Supervisor did not have knowledge of all the safety requirements for the work and did not communicate the requirements to the workers.	The Service Supervisor was not aware of requirements for all the permits involved, did not supervise welders prior to this work, and did not communicate safety precautions for all aspects of the job to the different crafts.
Workers perform welding/cutting operations in K-33 Building while wearing normal work coveralls.	Workers had only recently begun to remove converters under the new requirements and conditions associated with radiological personal protective equipment requirements, which require multiple layers of anti-contamination clothing.	Workers were not experienced in working in multiple layers of personal protective equipment (e.g., anti-contamination clothing, full-face respirator).	Workers and supervisors did not identify or fully understand the additional risks created by the multiple layers of personal protective equipment (e.g., anti-contamination clothing, full-face respirator, and welder's mask).
Site operating under normal conditions without downsizing or mission transition.	Site operating in a downsizing mode with changing missions and decreased morale.	Fewer experienced and knowledgeable personnel, high stress, low morale, new mission and responsibilities.	Workers, supervisors, and management were distracted, and the core competency base of the workforce was shrinking due to the turnover, transition, and downsizing.

2.6 CAUSAL FACTORS

The **root causes** of the accident (the fundamental causes that, if eliminated or modified, would prevent recurrence of this and similar accidents) were (1) personal protective equipment worn by the Welder was not identified as a hazard (i.e., the personal protective equipment was not flame-retardant) and (2) personnel safety responsibilities for the fire watch were not appropriately emphasized. The combination of these causal factors was the primary reason the Welder (working alone) was susceptible to a fire hazard from the cutting/welding operations he was performing at the time of the

The root causes of the accident were lack of flame-retardant protective clothing and lack of an effective fire watch.

accident. Because protective barriers for the hazard were not in place, the fire became uncontrollable, and the Welder was unable to extinguish it alone.

These root causes, if eliminated or changed, would not only prevent recurrence of this accident at other DOE sites, but also, if eliminated on the day of the accident, would have prevented the accident. It is recognized that, analytically, both of these root causes could be taken to a higher level (i.e., the policy level within DOE, Federal regulations, and LMES K-25 policies, which do not specifically address either of the concerns). The Board believes that presenting the root causes at this higher level will not be helpful to those in the field who have to implement lessons learned for this accident. Stating the root causes more directly emphasizes the true nature of the accident's causes. However, the Board has taken the issue of specificity in policy into account in constructing the judgments of need.

The issue of specificity in policy was also considered in developing judgments of need.

There were also **contributing causes** (causes that increased the likelihood of the accident without individually causing the accident, but that are important enough to be recognized as needing corrective action). The causal factors are identified on Table 2-2, with a short discussion for each factor.

Table 2-2. Causal Factors Analysis

Root Causes	Discussion
Personal protective equipment was not identified as a potential hazard (i.e., the personal protective equipment was not flame-retardant).	Federal regulations, DOE Orders/rules, and LMES K-25 policies do not identify the need or requirements for flame-retardant personal protective equipment for welding/cutting operations. The Board believes that if the anti-contamination clothing worn by the Welder had been treated with a flame retardant, the fatality would not have occurred.
Personnel safety responsibilities for the fire watch were not appropriately emphasized.	Federal regulations, DOE Orders/rules, and LMES K-25 policies do not address personnel safety protection as a responsibility of the fire watch. If a fire watch had been present, with clear responsibilities for personnel protection, the Board determined that, even without flame-retardant clothing, the fatality would not have occurred.
Contributing Causes	Discussion
Multiple levels of personal protective equipment created an additional hazard.	The use of multiple layers of clothing resulted in a bulky garment package with many folds and creases that could capture sparks or molten slag. These layers of clothing produced an undesired insulating effect and reduced the Welder's ability to recognize (by sensing heat) that he was on fire. In addition, the respirator and welding mask impaired the Welder's peripheral vision and sense of smell. The Board believes that the amount of personal protective equipment worn increased the Welder's risk from a fire hazard and contributed to the accident.

Table 2-2. Causal Factors Analysis (Continued)

Contributing Causes	Discussion
Lack of reporting of clothing fires contributed to incomplete hazard recognition.	Previous clothing fires had occurred but had not been reported to management. Although workers are required by LMES procedures to report all safety concerns to their supervisors so that management may be aware of such safety issues, the Board believes that workers' acceptance of the risk and their fear of losing their jobs due to recent downsizing and reorganizations may have resulted in these safety issues not being reported. In addition, management did not foster an atmosphere that encouraged reporting of incidents. The Board believes that because the incidents were not reported, management did not have sufficient data to understand the hazard and take appropriate action.
LMES failed to: (1) adequately plan the work, (2) provide adequate procedures, and (3) implement existing procedures.	The requirements of the work planning process were not adequately implemented; the work was classified as "routine maintenance" within the "skill of the craft," even though the workers had no recent experience in converter removal. The work involved a variety of personnel hazards and had not been performed on a routine basis since 1985. A Job Hazards Analysis was not performed. The existing work permitting process was also not followed. The hazard controls did not address all hazards present at the work site. Work planning processes, including a Job Hazards Analysis, work plan, and pre-job safety meeting, should have been performed.
Line management responsibility and accountability for safety were not adequately defined for OR and LMES.	Management failed to ensure that workers and supervisors were properly qualified and trained to perform assigned tasks and that appropriate roles and responsibilities for safety were established and communicated. The Board believes that the lack of clearly defined roles and responsibilities for safety contributed to the accident.
Due to lack of oversight by OR and LMES, the opportunity to identify the hazard was missed.	There were no assessments and direct observations of the job by management, safety personnel, or DOE. The Board believes that had there been some oversight by the health and safety organizations or by the project management organizations (e.g., supervisor), the numerous clothing fires might have been observed and corrective actions taken.

3.0 CONCLUSIONS AND JUDGMENTS OF NEED

Conclusions are a synopsis of those facts and analytical results that the Board considers especially significant. Judgments of need are managerial controls and safety measures believed necessary to prevent or mitigate the probability or severity of a recurrence. They flow from the conclusions and causal factors and are directed at guiding managers in developing followup actions. Table 3-1 summarizes conclusions of the Board and judgments of need regarding managerial controls and safety measures necessary to prevent or mitigate the probability of a recurrence.

Table 3-1. Conclusions and Judgments of Need

CONCLUSIONS	PROPOSED JUDGMENTS OF NEED
<p>The selection of personal protective equipment failed to consider the potential hazards (e.g., fire) associated with the use of anti-contamination clothing during welding, burning, and hotwork operations.</p>	<p>There is a need for the Assistant Secretary for Environment, Safety and Health (EH-1) to review and issue, as appropriate, policy and standards that include requirements for flame-retardant anti-contamination clothing and personal protective equipment worn by workers conducting cutting, welding, and other hotwork operations.</p> <p>Concurrent with the EH-1 review, LMES should review and revise, as appropriate, its specifications for anti-contamination clothing to determine the need for including flame-retardant requirements for the clothing which is worn by workers during welding/cutting/hot- work operations.</p>
<p>The combination of multiple personal protective equipment (which restricted sensory perception), flammable anti-contamination clothing, and the absence of a dedicated fire watch significantly reduced the protective barriers against fire hazards.</p>	<p>There is a need for EH-1 to review and develop appropriate requirements similar to 29 CFR 1910.120, Appendix C, for all DOE work activities to emphasize that personal protective equipment can, by itself, create significant worker hazards, and that overprotection, as well as underprotection, should be avoided where possible.</p> <p>Concurrent with the EH-1 review, LMES needs to evaluate safety hazards for workers specific to each job and the risks that may be added by use of multiple controls or personal protective equipment, in accordance with the requirements in the LMES K-25 Site Radiological Control Manual.</p> <p>There is a need for EH-1 to review and revise existing DOE policy regarding the responsibilities of fire watches to ensure that both worker safety and property loss prevention are considered.</p> <p>Concurrent with the EH-1 review of fire watch policy, LMES needs to review and revise, as appropriate, its fire watch program, procedures, and training to clearly identify that:</p> <ul style="list-style-type: none"> • Fire watch responsibilities include both worker safety and property loss prevention, • Fire watches must always be in a position to detect a fire and provide adequate emergency response for the worker, and • Fire watches must be trained in appropriate response and provided with appropriate fire protection equipment (e.g., extinguishers, blankets, radios) that is immediately accessible and available for use.
<p>The burn test conducted at the direction of the Board confirmed that the clothing worn by the Welder burned quickly and that the multiple layers of clothing insulated him from sensing the heat of the fire, seriously precluding his ability to extinguish the fire by himself.</p>	<p>None.</p>

Table 3-1. Conclusions and Judgments of Need (Continued)

CONCLUSIONS	PROPOSED JUDGMENTS OF NEED
<p>Precursors (e.g., near-miss clothing fires) occurring during welding and cutting operations similar to this accident were not recognized as safety hazards and reported.</p>	<p>There is a need for OR and LMES to foster and assure a work environment (including positive incentives) in which workers will report injuries and near-miss incidents through supervision to management.</p>
<p>The LMES planning process for the K-33 converter removal work did not ensure that an adequate Job Hazards Analysis was completed before work started. Therefore, controls to mitigate all the work hazards were not developed or implemented.</p> <p>Failure by LMES to provide adequate procedures and to effectively implement those in place prevented a clear understanding of expectations and the associated requirements for the work on the day of the accident.</p> <p>Lessons learned from previous and similar activities were not adequately evaluated, documented, or incorporated by LMES into the work planning for the K-33 converter removal work.</p>	<p>There is a need for LMES to strengthen existing work planning processes, including procedures and training, to ensure: (1) existing LMES instructions are used for performing a Job Hazards Analysis, which includes the identification of hazards and controls with each step of the work to be performed; (2) pre-job safety meetings are conducted with crafts people performing the work, appropriate safety personnel monitoring the work, and supervisors present; (3) clear criteria are established for work categories (e.g., routine, non-routine) that are based on the hazards and complexity of the work to be performed; (4) lessons learned are integrated into work planning and communicated to all project personnel; and (5) adequate supervision of the work.</p> <p>There is a need for LMES to clearly define in the Safety Work Permit Procedure that the Issuing Authority has the responsibility to assure that a Job Hazards Analysis is prepared in accordance with LMES instructions.</p>
<p>Neither the service supervisor who signed the Burning Permit nor the Issuing Authority, who also should have signed the Burning Permit governing the work activities, was trained in the importance of designating a fire watch and documenting it on the Permit.</p>	<p>There is a need for LMES to clarify the roles and responsibilities of K-25 issuing authorities, service supervisors, and other first-line supervisors relative to requirements, expectations, and understanding of the permitting process.</p> <p>There is a need for LMES to assure that issuing authorities, service supervisors, and other first-line supervisors at K-25 are adequately trained and have the requisite skills and knowledge to carry out their responsibilities in the work-planning and control process.</p>
<p>OR personnel below the first level of management involved in the K-33 converter removal “work for others” activity did not have clear expectations and understandings regarding their responsibilities and authorities for safety.</p>	<p>OR needs to ensure that roles, responsibilities, and authorities for management and safety are clearly defined, understood, and implemented at all levels by personnel (including those at site offices under OR cognizance) involved in planning, monitoring, and oversight of “work for others” projects.</p>
<p>LMES personnel below the Oak Ridge Site Management (K-25) level involved in the K-33 converter removal “work for others” activity did not have clear expectations and understanding regarding their responsibilities and authorities for safety.</p>	<p>There is a need for LMES to clearly communicate roles, responsibilities, and authorities for safety and oversight through all organizational levels, including line management and staff.</p>

Table 3-1. Conclusions and Judgments of Need (Continued)

CONCLUSIONS	PROPOSED JUDGMENTS OF NEED
LMES has not effectively implemented its written commitment that line management is responsible for safety. Downsizing, organizational changes, and procedural inadequacies have created voids in line management, resulting in the absence of overall direction and a single focal point for the K-33 converter removal work who would be responsible for and knowledgeable of all activities involved.	LMES needs to put its written commitments into action, implementing a safety management system that establishes clear accountability for safety throughout all levels of the organization.
The overall quality of the accident response, even considering the lighting and egress problems, was satisfactory and provided the Welder opportunity for survival, had the burn wounds not been so extensive.	None.

4.0 BOARD SIGNATURES

Fred J. Volpe

DOE Accident Investigation Board Chairperson
U. S. Department of Energy
Office of Environment, Safety & Health

Date: _____

Robie L. Monroe

DOE Accident Investigation Board Member
U. S. Department of Energy
Office of Environment, Safety & Health

Date: _____

Carl A. Caves, P.E., C.S.P

DOE Accident Investigation Board Member
U. S. Department of Energy
Office of Environment, Safety & Health

Date: _____

Randall C. Smyth

DOE Accident Investigation Board Member
U. S. Department of Energy
Office of Environmental Management

Date: _____

Charles T. Williams

DOE Accident Investigation Board Member
U. S. Department of Energy
Oak Ridge Operations Office

Date: _____

Craig H. Booker

DOE Accident Investigation Board Member
U. S. Department of Energy
Oak Ridge Operations Office

Date: _____

5.0 BOARD MEMBERS, ADVISORS, AND STAFF

Chairperson	Fred J. Volpe, DOE, EH-24
Member	Robie L. Monroe, DOE, EH-24
Member	Randall C. Smyth, DOE, EM-46
Member	Charles T. Williams, DOE, Oak Ridge
Member	Craig H. Booker, DOE, Oak Ridge
Member	Carl A. Caves, DOE, EH-22
Advisor	Dennis L. Vernon, DOE, EH-21
Advisor	Dennis Kirson, DOE, Albuquerque
Advisor	Larry D. Perkins, Paragon Technical Services
Analytical Support	Jeffrey S. Oakley, Battelle Oak Ridge
Analytical Support	Ray T. Moore, DOE, Oak Ridge
Technical Writer	Dale A. Moul, Battelle Columbus
Technical Writer	Michael A. Duffy, Battelle Columbus
Technical Editor	Kathleen H. Moore, Battelle Columbus
Medical Advisor	William H. Greendyke, M.D., Consultant
Legal Advisor	Ray Miskelly, DOE, Oak Ridge
Union Observer	John W. Steward, OCAW, Oak Ridge
Union Observer	Bruce D. Lawson, OCAW, Oak Ridge
DNFSB Observer	Don F. Owen, DNFSB Staff
Administrative Support	Barbara S. Harshman, DOE, EH-21
	Elizabeth A. Curtiss, Battelle Columbus
	Charlotte Textor, Battelle Oak Ridge

APPENDIX A
APPOINTMENT MEMO FOR TYPE A ACCIDENT INVESTIGATION

APPENDIX B

PERFORMANCE OF BARRIERS

Appendix B. Performance of Barriers

Barrier	Purpose	Performance
Work Planning	To develop the work activities, identify and evaluate hazards, and establish safety practices for the work to be performed.	Barrier failed because the work was considered “routine,” and no Job Hazards Analysis or work plan was developed.
Job Hazards Analysis	To identify hazards associated with the work activities and evaluate and specify health and safety requirements, as required in LMES procedures, instructions, and permits related to work planning.	Barrier failed because coordinated, interdisciplinary inspection and evaluation was not performed to recognize the hazards for the work activity.
Training	To ensure that personnel involved with certain activities are cognizant of the job requirements, procedures, permits, and safety practices required to perform tasks safely.	Barrier failed because training was not required for the Service Supervisor and Issuing Authority on the Burning Permit process; therefore, they did not understand the process and the importance of assigning a fire watch.
Lessons Learned/Communication	To provide information from similar work activities or previous accidents to ensure that hazardous situations can be identified and avoided.	Barrier failed because the lessons learned from previous, similar work were not used by management in the K-33 work. Workers were not reporting injuries and near misses.
Direct Supervision	To provide direction to workers and monitor their activities.	Barrier failed because supervision did not understand its role, provide direction, and discharge its responsibilities in monitoring work activities.
Management	To assure that there is a structured and integrated safety management system with clearly defined roles, responsibilities, and authorities for safety.	Barrier failed because management responsibilities for safety were poorly defined, not communicated, and not understood. As a result, clear and rigorous safety processes and practices were not in place, not understood, or not followed.
Oversight (OR and LMES)	To assure that project work is accomplished safely in accordance with applicable requirements.	Barrier failed because responsibility for safety oversight was not understood or implemented.
Fire Watch	To provide a trained individual who is dedicated to observing welding, burning, and hotwork activities for the purpose of providing an additional level of protection from hazards.	Barrier failed because no fire watch was assigned. Policy for fire watch does not place emphasis on personnel protection.

Appendix B. Performance of Barriers (Continued)

Barrier	Purpose	Performance
Personal Protective Equipment	To protect workers from hazards associated with specific jobs and work activities.	Barrier failed because personal protective equipment selected was not fire-retardant. Federal regulations, DOE Orders/rules, and LMES K-25 policies were not established for fire-retardant materials. Multiple layers of equipment provided loss of sensitivity (sight, smell, feel) to fire/heat.